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RESEARCH
— on the —
Corrosion Resistance
of
Copper Steel

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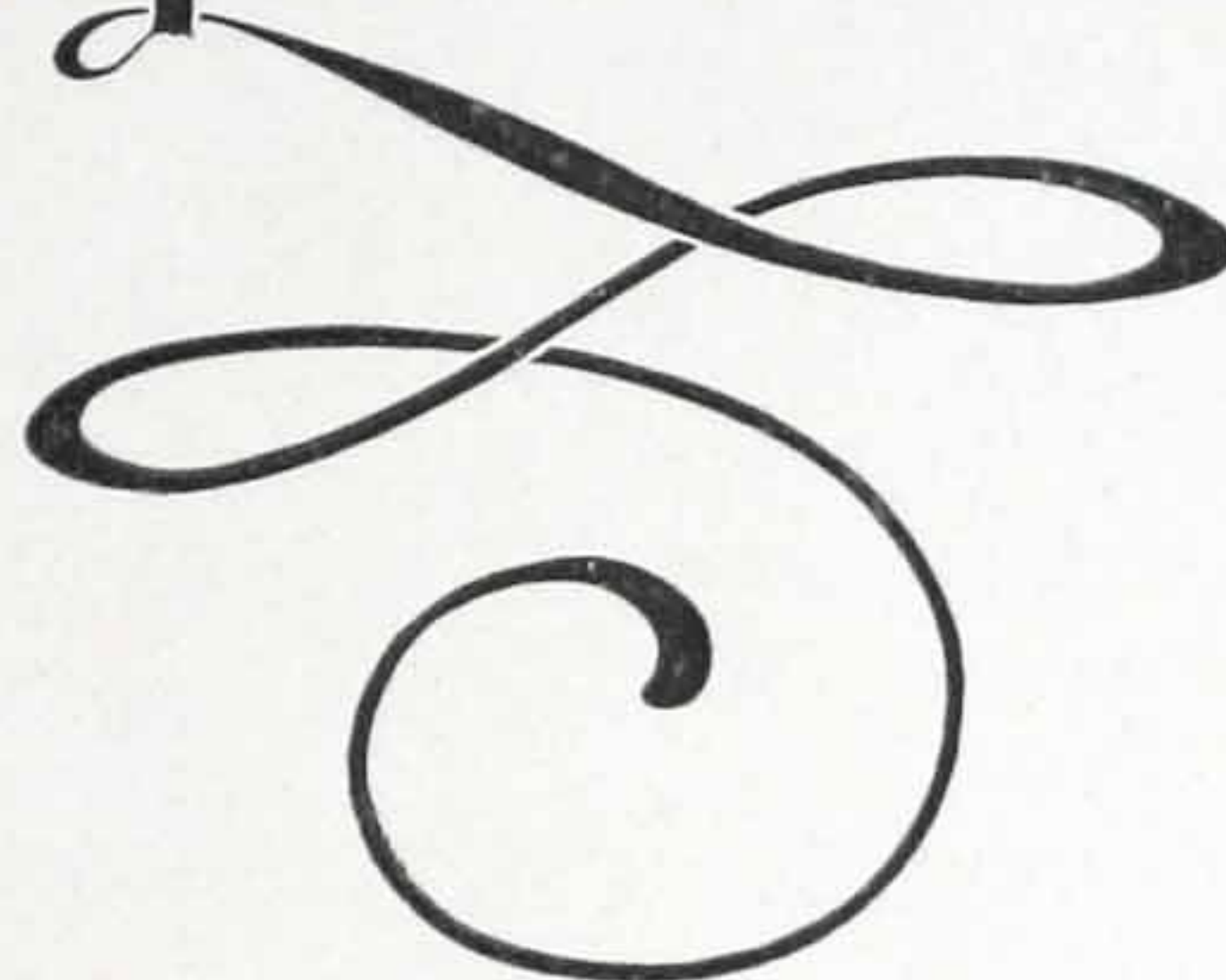
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Corrosion Resistance of Copper Steel



—BY—

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Synopsis

1. Copper increases the resistance of steel and iron to atmospheric corrosion.
2. Its influence is apparent when the copper content reaches .03%.
3. Its effect is almost at a maximum when the copper reaches .05%.
4. .25% copper has been chosen as the best amount for commercial steel.
5. Steel containing .25% copper outlasts "pure iron" containing .05% copper.
6. Steel containing .05% copper lasts as long as "pure iron" containing .05% copper.
7. The influence of copper is probably due to its control of the sulphur.
8. Sulphur in steel accelerates corrosion very markedly.
9. Sulphur oxides in the air accelerate the corrosion of steel.
10. Copper in steel counteracts or retards both corroding influences.

Research on the Corrosion Resistance of Copper Steel

BY

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Published in JOURNAL OF INDUSTRIAL AND ENGINEERING CHEMISTRY, (AMERICAN CHEMICAL SOCIETY,) March, 1916.

In order to obtain further definite information relative to the influence of varying amounts of copper and other elements when alloyed with steel, an extended series of service tests was undertaken by the authors in the spring of 1914.

Following work which had been done by one of us,* we continued the practice of conducting the tests on full size, uncoated sheets, under exact service conditions, extreme care being taken so to plan the work that whatever differences might be found between the various grades of steel used, they could safely be ascribed to the influence of the particular element which had been added.

In addition to repeating work, which had already been done, on the effect of the addition of approximately one-quarter of one per cent. of copper, we included in this test, steels with copper content as low as .04 percent., as well as steels with higher amounts up to and including 2 percent.

As will be seen from the following tables, we also made additions of phosphorus, silicon, aluminum, sulphur, roll scale, and, following a suggestion of a colleague** that the addition of cold steel to the middle ingots of the heat would cause them to outlast the first poured ingots, a similar amount of cold steel turnings was added to one of the ingots in exactly the same manner in which copper had been added to the others.

*Journal of Industrial and Engineering Chemistry, June, 1913; Iron Age, June 3, 1915; Iron Trade Review, June 10, 1915.

**Bulletin 5—Institute of Industrial Research.

Some work has also been done on the influence of annealing temperatures higher than the average practice, and we have kept careful records of inside and outside sheets of the pack,*** and of the presence or absence of mill scale on the surface of the sheets at the time of exposure, to determine whether or not these differences in initial protection affected the time of ultimate failure of the sheets.

Several heats of Open Hearth and Bessemer steels were used in the tests and the following list gives the additions as they were made. It will be noted that in one instance, ten ingots were used from a single heat, and that they differed one from the other only in the amount and kind of element which was added. In later tables we give the final analyses of the sheets rolled from these ingots. The grade numbers given here are used throughout this paper.

Basic Open Hearth Heat No. 6807

GRADE	INGOT No.	ADDITION
.....	1	None made. Ingot not used.
2	2	Copper aiming at .25 percent.
3	3	Copper aiming at .50 percent.
4	4	Copper aiming at 1.00 percent.
5	5	Copper aiming at 2.00 percent.
6	6	Plain steel. No addition. Used for test.
7	7	Phosphorus aiming at .100 percent.
8	8	Silicon aiming at .300 percent.
9	9	Aluminum, 8 ounces.
10	10	Sulphur aiming at .100 percent.
11	11	Cold steel, 16 lb.

***Sheets are rolled in packs and the two outside sheets of the pack always carry on their surfaces much more mill scale (magnetic oxide of iron) than do the inside sheets.

Basic Open Hearth Heat No. 8815

Approximately one-half of the heat was run into a ladle and copper added aiming at .25 percent.

GRADE	INGOT No.	ADDITION
12	2	Copper to ladle; aiming at 0.25 percent.

The remainder of the heat was run into another ladle without copper addition, and while casting, copper was added to one ingot.

GRADE	INGOT No.	ADDITION
13	2	Copper to mould; aiming at 0.25 percent.
14	3	Plain steel. No addition.

High Sulphur Bessemer Heat (Residual, Not Added, Sulphur)

GRADE	INGOT No.	ADDITION
15	---	Copper aiming at .25 percent.
16	---	Plain steel. No addition.

Normal Bessemer Heat

GRADE	INGOT No.	ADDITION
17	---	Copper aiming at .25 percent.
18	---	Plain steel. No addition.

Basic Open Hearth Heat No. 7750

In the manufacture of this heat, an effort was made to produce a wild, oxidized heat. The steel was melted "hot;" ore was fed faster than usual and continued, even after carbon had been reduced to .12 percent. Silica sand was added instead of dolomite. The heat had a very wild appearance, rose strongly in the moulds, and in addition, we had a running stopper in the ladle which gave a divided stream which of course favored oxidation. Analyses of the sheets from this heat by the Ledebuhr method showed an oxygen content averaging only .03 percent., which is no higher than in normal Open Hearth Steel.

GRADE	INGOT No.	ADDITION
19	4	Copper aiming at .25 percent.
20	6	Copper aiming as above, and roll scale, 20lb.
21	7	Roll scale, 20 lb.
22	8	Silicon aiming at .10 percent.
23	9	Phosphorus aiming at .10 percent.
24	3	Plain steel. No addition.

Basic Open Hearth Heat No. 8857

This heat was made without the addition of manganese or other deoxidizer at any stage.

GRADE	INGOT No.	ADDITION
25	2	Plain steel. No addition.
26	3	Copper approximating .35 percent.

Basic Open Hearth Heat No. 8805

This heat corresponds to heat No. 6807 (Grades 2 to 11 inclusive) and the same additions were made in exactly the same way and in the same order. The composition is quite similar to No. 6807 *except that the copper (residual) is about .04% in all grades but those to which copper was added.*

Comparing the results on sheets from this heat with those from heat No. 6807, we obtain information relative to the influence of comparatively small copper content.

The grade numbers for heat No. 8805 are the same as for No. 6807 except that an "X" has been added to each.

Basic Open Hearth Heat No. 7699

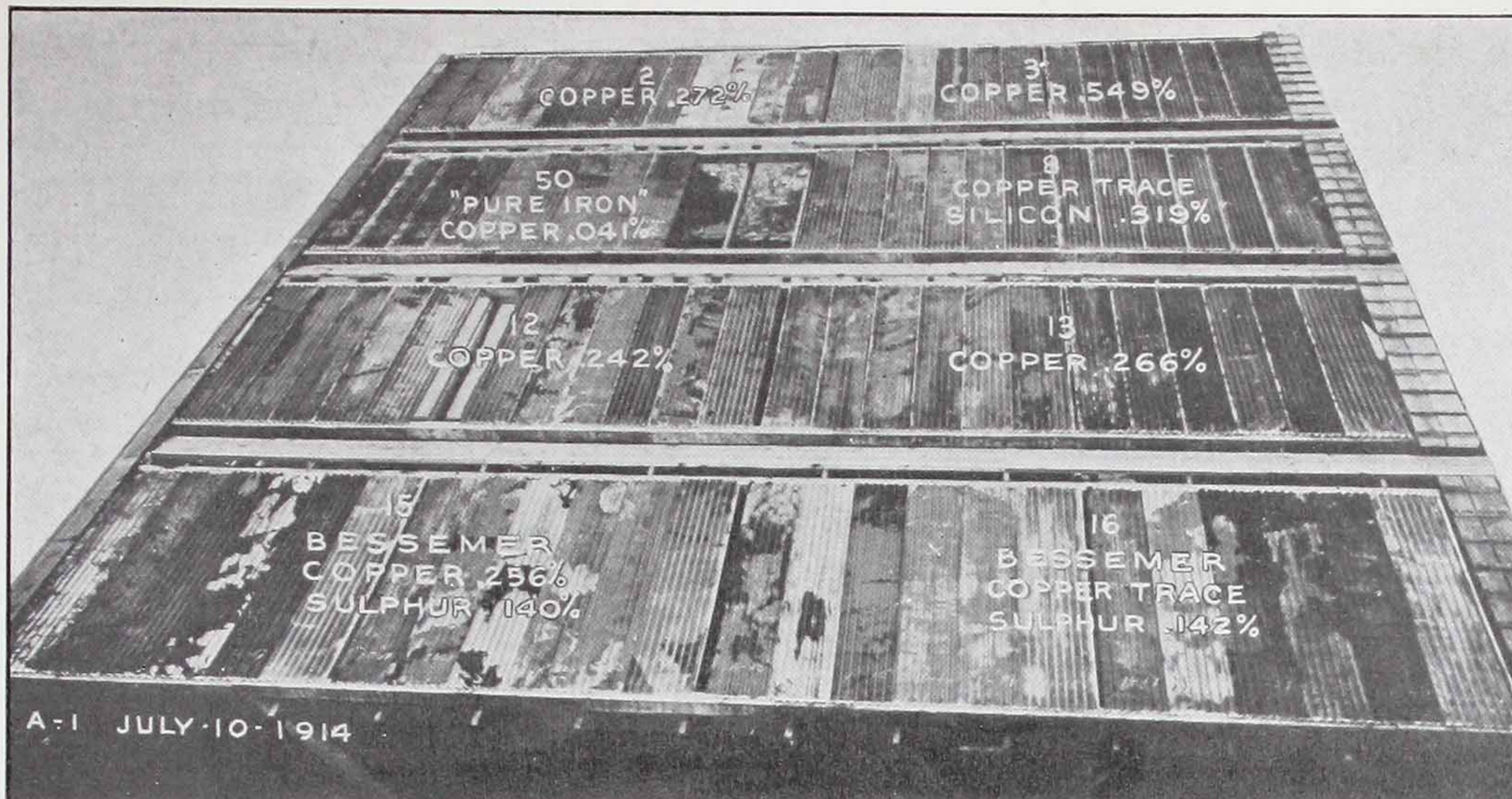
This heat corresponds to heat No. 8815 and the additions were the same. This heat, however, contained .05 percent. residual copper. Grade numbers are 12X, 13X and 14X.

Methods of Sheet Manufacture

All of the operations of blooming, rolling, sheet rolling, etc., were conducted according to regular mill practice and were under the personal supervision of the authors.

Enough sheet bars were taken from the product of each ingot to give us a large excess of sheets for our tests. The bars were taken from the piles at such points as to represent the whole ingot from top to bottom, thus securing the average product of the ingot.

All grades were given exactly the same treatment in all of the manufacturing operations, and each sheet received the



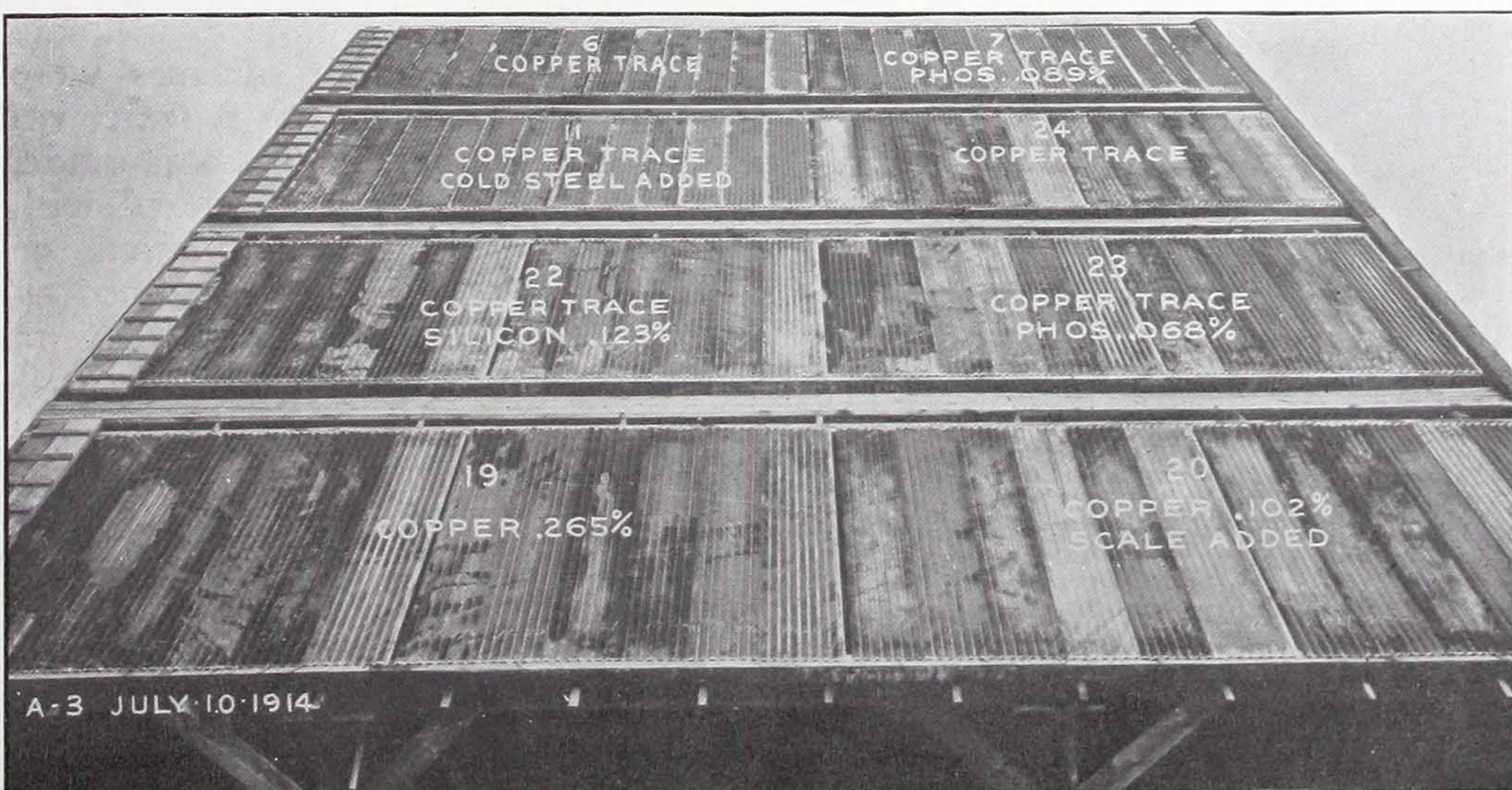
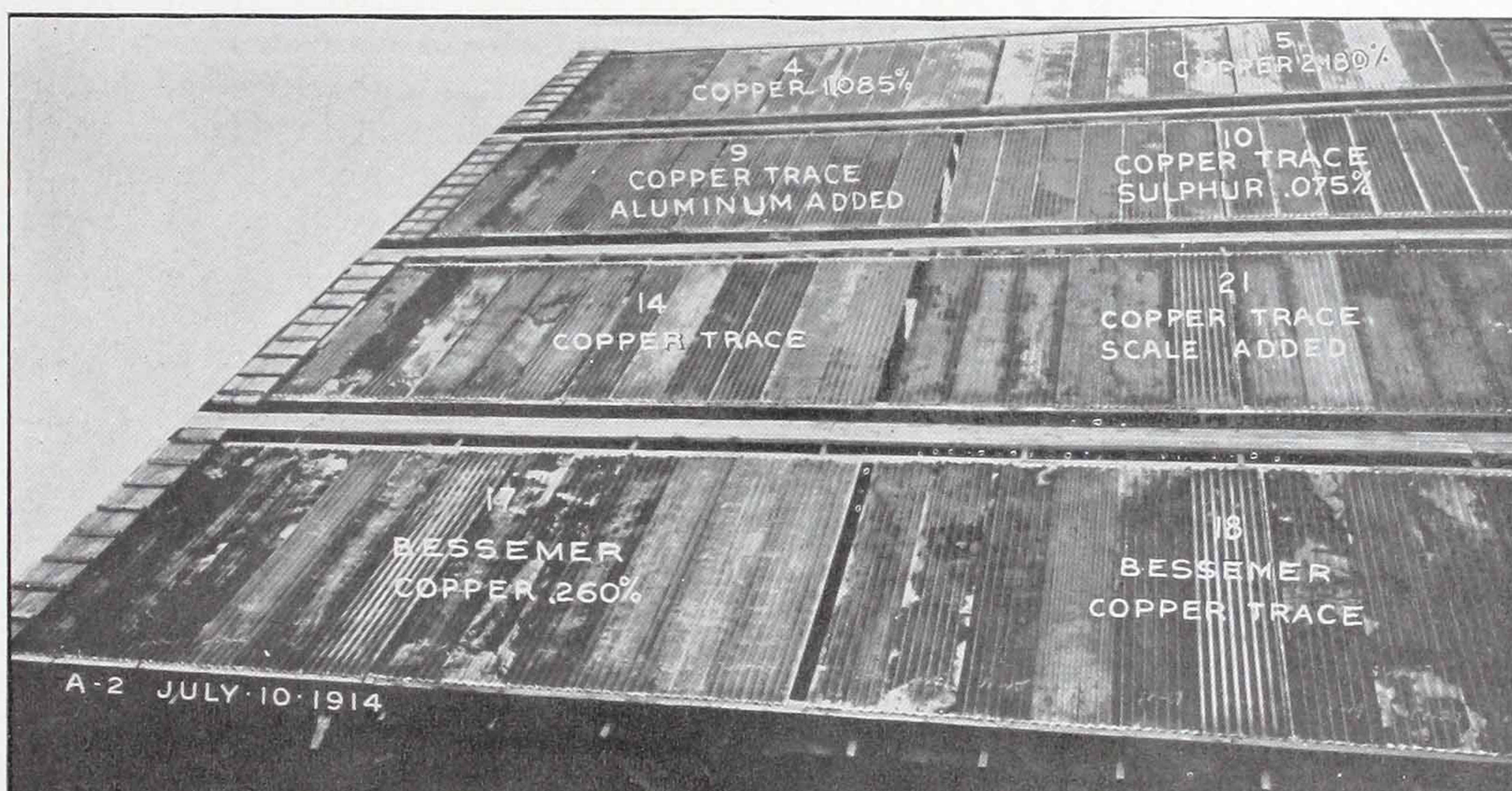
FIGS. A 1—2—3.

Scottdale Test

(Pennsylvania Coke region).

Photographs taken a few hours after sheets were exposed.

(Mottled appearance of sheets due to presence and absence of mill scale).



customary one (straightening) pass through the cold rolls.

All sheets, (except those which were annealed at higher temperature,) were annealed at one time in the same furnace, thus securing uniform heat treatment.

To determine the possible influence of higher annealing temperature, one-half of the sheets of grades 2 to 14 inclusive were annealed at a temperature about 200 degrees F. higher than the normal temperature for sheets. The remainder of the sheets of these grades and all other grades were annealed at the usual temperature.

After the annealing process the sheets were laid out in piles and the twenty-four (24) sheets of each grade required for our tests were taken at regular intervals from the piles, an average product thus being obtained.

Each sheet was stamped with a distinguishing mark, and they were numbered consecutively from 1 to 24. In the case of the grades 2X to 14X inclusive, and also grades 25 and 26,—six sheets of each were selected in the same manner as above, and were numbered from 1 to 6. All sheets were 26 guage, 26" x 96".

A strip 2" wide was cut lengthwise from each sheet, and these strips were given the same distinguishing numbers as the sheets from which they were cut, and were sent to the laboratories, where *each one* was carefully analyzed.

As soon as this work had been completed, and we were thus assured that no mistakes had been made in marking the sheets, they were corrugated and forwarded to Scottdale and McKeesport, Pennsylvania.

Twelve sheets of each of grades 2 to 24 inclusive, were exposed at each station, while the other grades 2X to 14X, 25 and 26 were exposed at McKeesport only.

There had meanwhile been obtained in the open market, from three different sources, three lots of one of the so-called "pure irons," which on analysis proved to have a copper content of .041%. Several sheets of each lot were taken and exposed

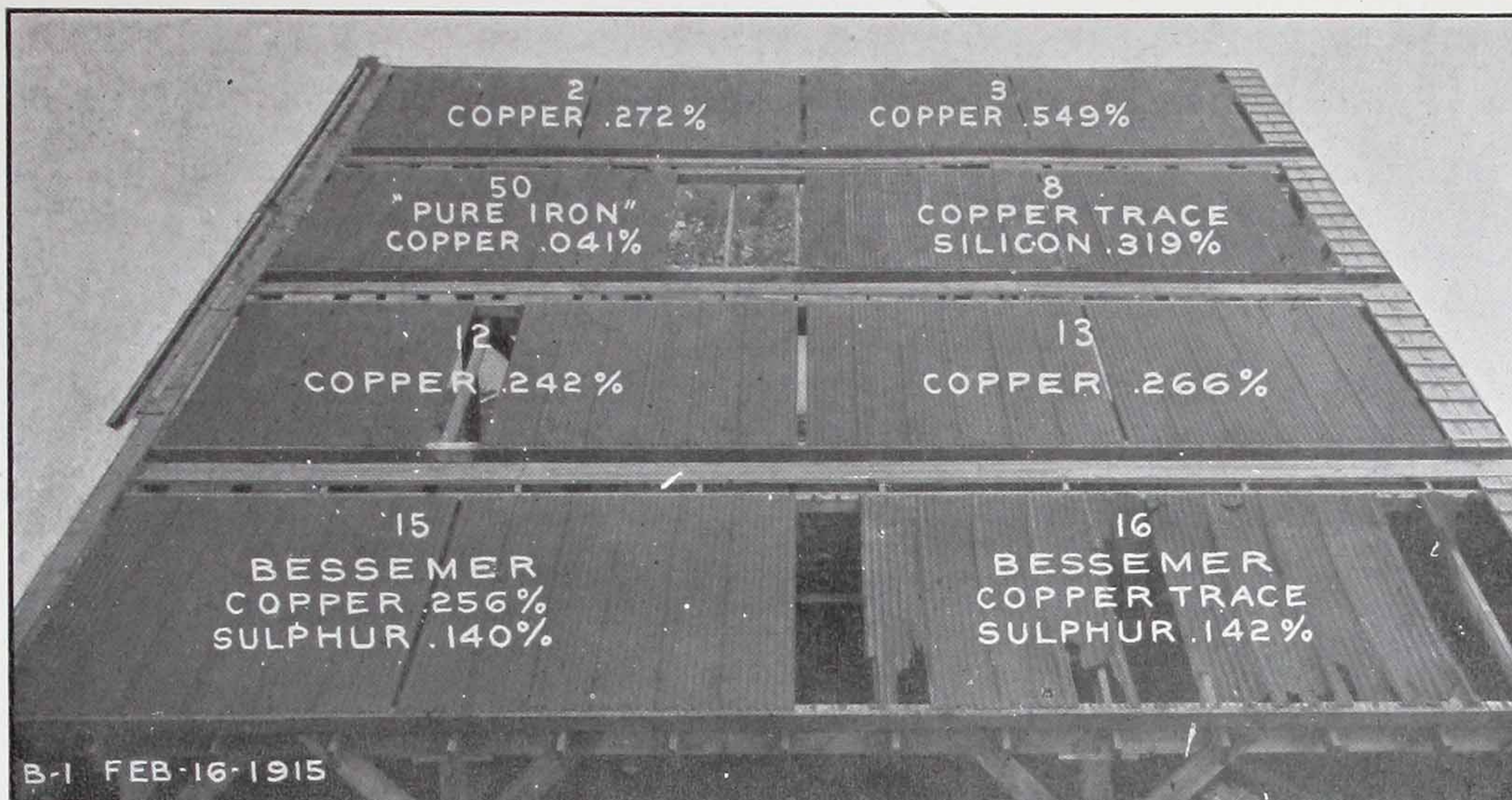
exactly as received, without pickling or cleaning of any kind. (This has been our invariable practice with all corrugated sheets of all grades in this test and in previous tests made by either of us.)

All of the grades above mentioned, including the so-called "pure iron" (Grade 50) were exposed as roof panels at McKeesport on July 7th, 1914, and at Scottdale on July 9th, 1914. At approximately the same time that the full size sheets were exposed, a series of 2" x 4" test pieces cut from the 2" strips before mentioned, and consisting of one piece from each sheet (636 in all,) was exposed. These test pieces were cleaned by a very light wash of sulphuric acid, dipped in ammonia water to neutralize all acid, then thoroughly washed, dried, weighed and arranged in wooden racks in such a manner as to afford all free and equal exposure to the weather.

The method of removing, cleaning and weighing these test pieces will be discussed later. The results obtained are given in the various tables submitted herewith.

Referring, for the present, to the full size corrugated sheets shown in the cuts, careful notes were taken at the time of exposure concerning the physical appearance of the sheets as affected by the amount of mill scale which was present, and as to whether they were outside or inside sheets of the packs. During the progress of the test, this feature was carefully watched, and the time of ultimate failure of sheets whose surfaces were comparatively free from mill scale was compared with others of the same grade, whose surfaces were well covered with mill scale. From these observations, we conclude that the influence of this original surface oxide is slight, and is lost in the early stages of rusting, for no differences in final failure could be noticed.

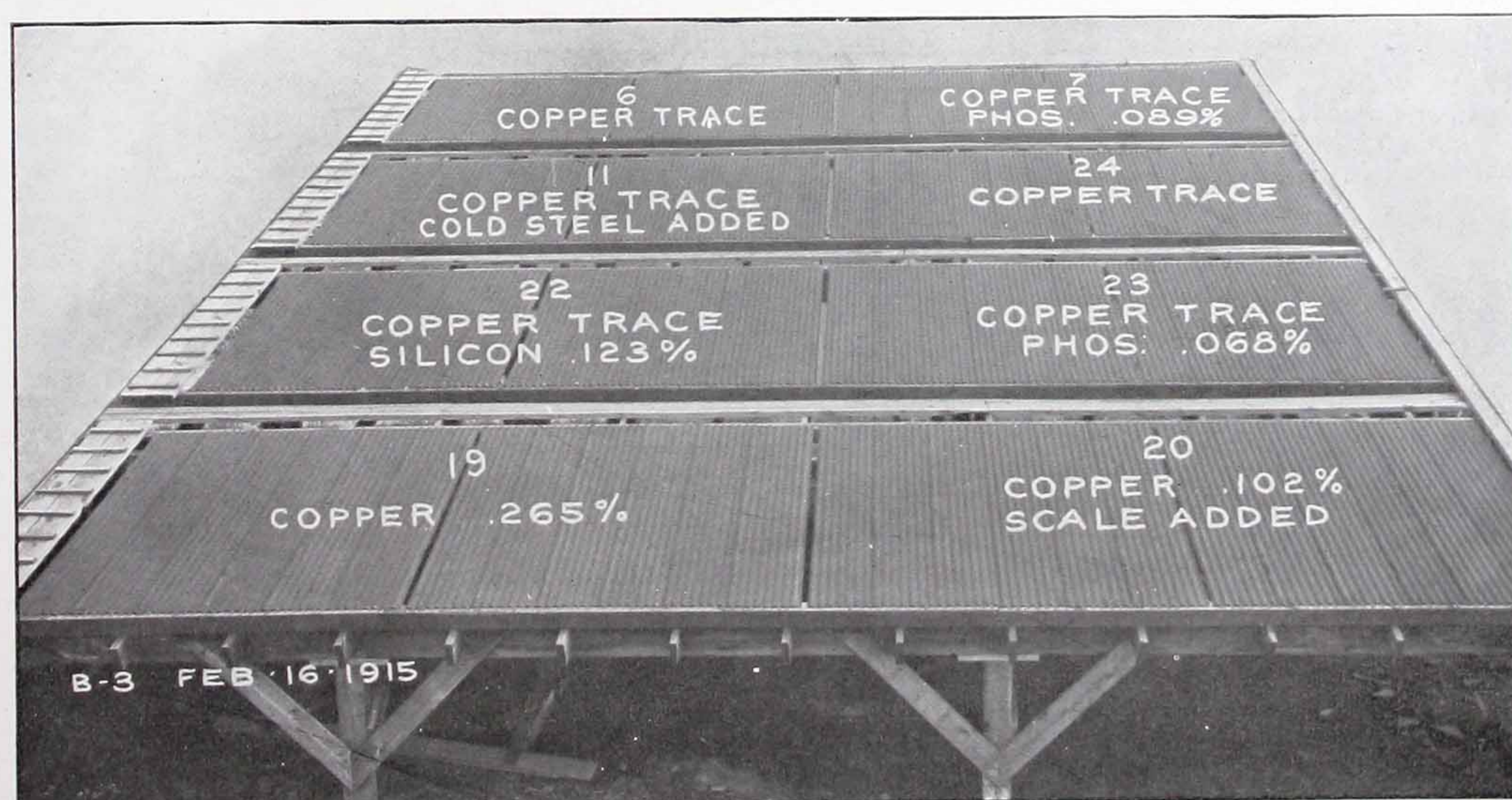
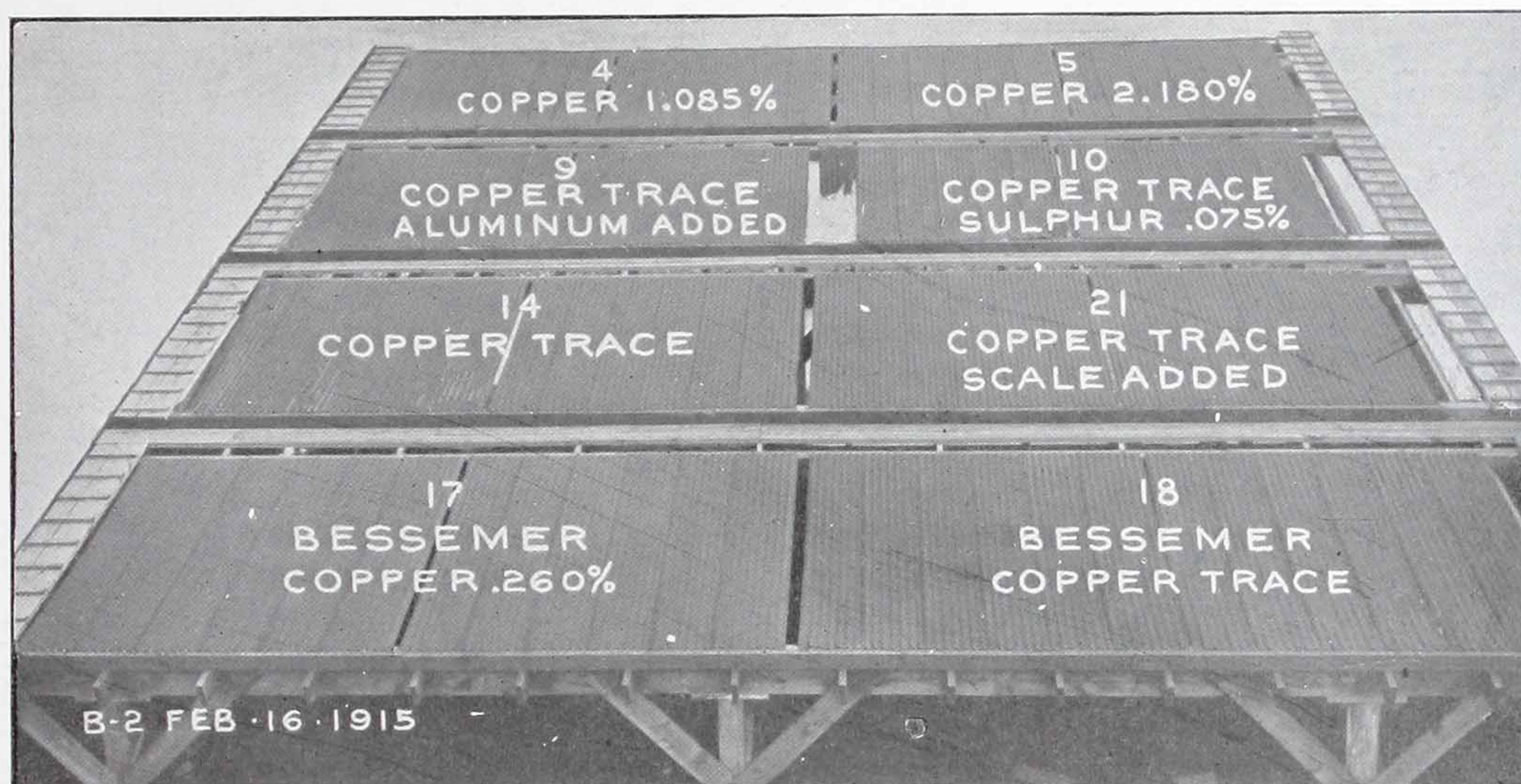
In the cases of panels 2 to 14 inclusive, one-half (6 sheets) of each grade were from the lot which had been annealed at approximately 1400° F, and the other six from the lot annealed at approximately 1600° F.



FIGS. B 1—2—3.

Scottsdale Test

After about seven
months exposure.



The photographs submitted herewith were taken from time to time during the tests, and show in a graphic manner the progress of the corrosion at various stages.

Careful inspections of the sheets were made approximately once every two months, and at the first inspection, distinct differences were noticed in the physical conditions of the various panels. The corrosive action of the atmosphere had produced a decided difference in color, the steels with a copper content of .25 percent, or more being distinctly darker than the others which contained only a trace of copper. At the same time, these dark brown panels were smoother to the touch than the others, and the rust was denser and more adherent. Inasmuch as this same phenomenon had been noticed in former tests, it was indicated even at this early stage, which steels would be the most resistant. It was also noted that several of the panels to which ingredients other than copper had been added, for instance, sulphur and aluminum, gave indications that the rate of corrosion was proceeding even faster than with those steels to which no additions had been made.

The fact that such early inspections are valuable, and that the relative merits of the various steels and irons can be predicted with fair accuracy, is borne out by the results of later inspections, and by the order of failure of the various panels.

The peculiar piebald appearance of the sheets (photographs were taken immediately after exposure of the sheets) in cuts A-1, 2, and 3, is caused by the irregular distribution of mill scale. The outside sheets show a uniform dark color while the inside sheets are light in the areas where mill scale was absent and vice versa.

It will be noted that the twelve (12) sheet panels have been divided into two panels of six (6) sheets each. In the cases of grades 2 to 14 inclusive the left half of these consists of sheets annealed at 1400°, while those in the right half were annealed at 1600°. In all other

cases the two halves received identical annealing treatment.

Referring to cuts E-1, 2 and 3, an unusually severe wind storm occurred at Scottdale on November 18, 1915, which blew away all fragments of sheets which were hanging by one end, only those sheets remaining which were in good condition and which still contained a considerable amount of uncorroded metal.

The rates of corrosion of the various grades may be observed by studying the photographs A, B, C, D and E, of the Scottdale test, and F, G, H, and I of the McKeesport test.

We call particular attention to the photograph of the Scottdale test taken December 1st, 1915, seventeen months after the test was erected. At this time, all of the non-copper steels and the "pure iron" have completely failed, while every panel to which copper has been added is intact.

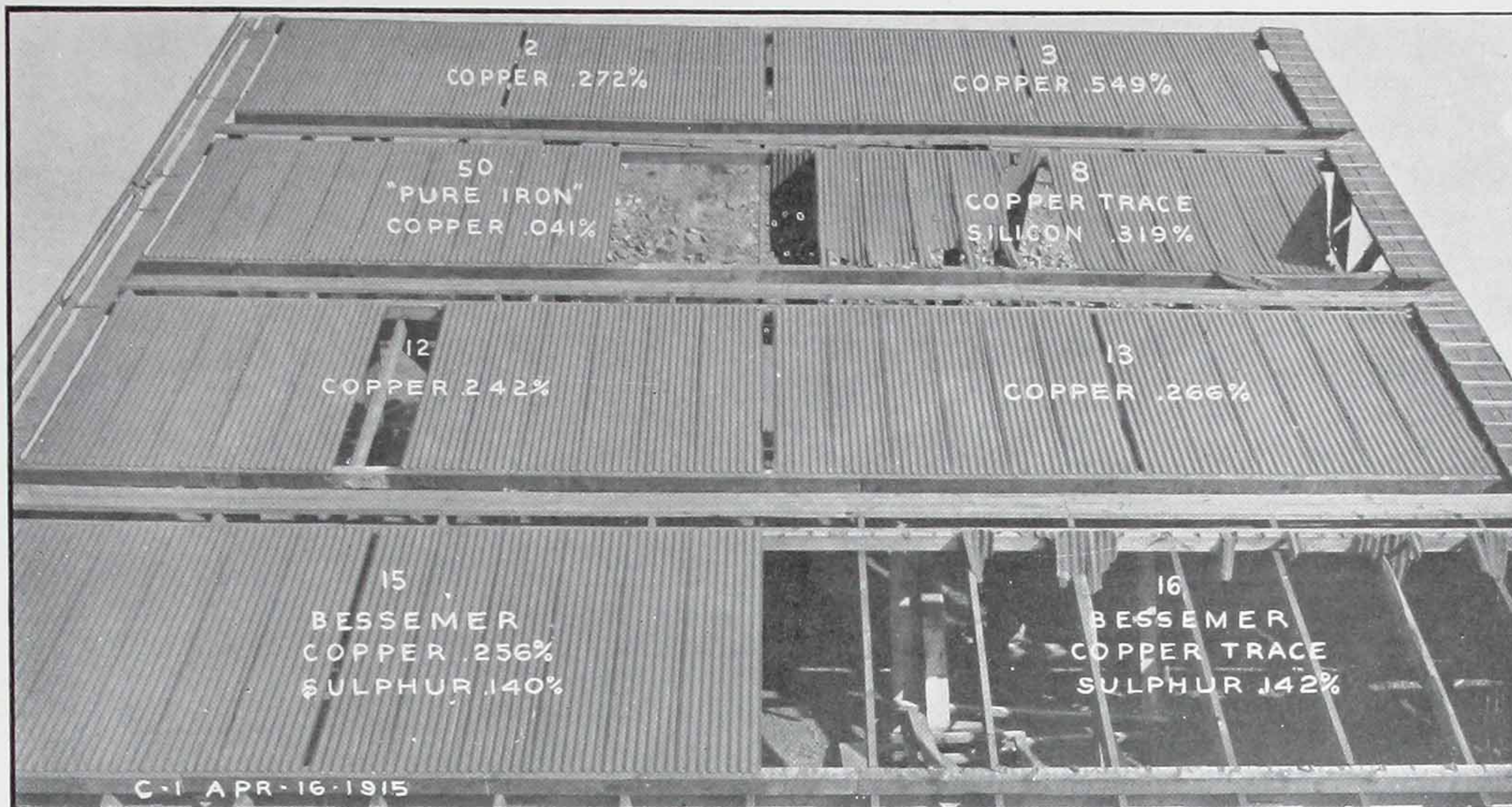
While the corrosion at McKeesport was somewhat slower than at Scottdale, yet by a study of the photographs and tables, it will be seen that the relations between the various grades are approximately the same.

It has been claimed* that tests made by determining the losses in weight on exposure of comparatively small test pieces are inaccurate and misleading.

A study of the tables which we present herewith, showing the weight losses due to corrosion of the various grades of steel and iron, in the shape of 2" x 4" test pieces, together with the photographs showing the conditions of the large size sheets, will prove that the results accord remarkably, and that the weight losses correspond to the relative endurance of the large sheets.

In these experiments, we have adopted the practice of removing and cleaning one-half of the small test pieces after the lapse of several months, allowing the others to remain exposed for some time longer. This was done in an effort to determine if there was any tendency of the rust film to behave differently on

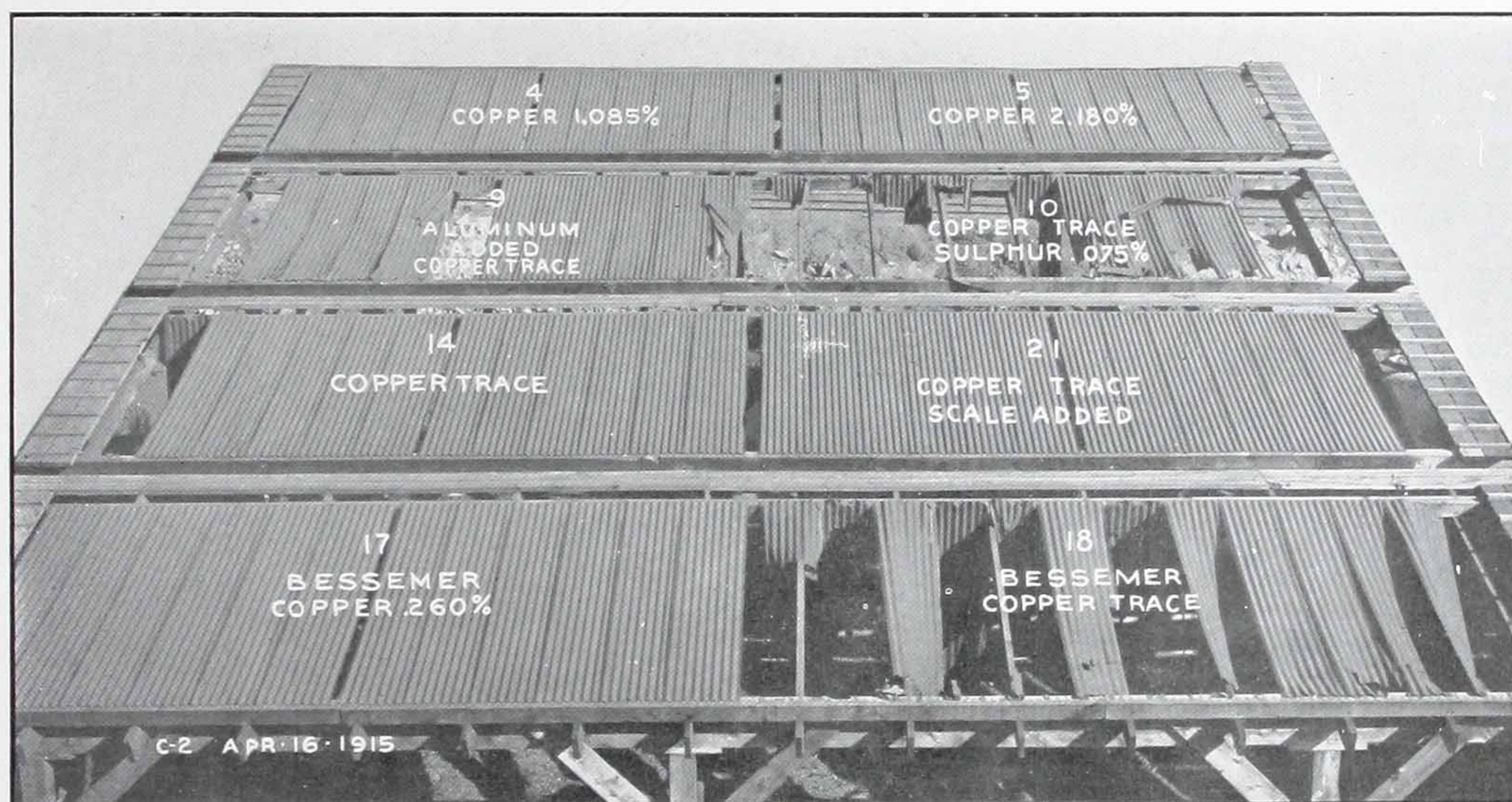
* Cushman; Proc. American Iron and Steel Institute, 1915.



FIGS. C 1—2—3.

Scottsdale Test

After about nine months exposure.



different sheets. It was thought that the sponge-like rust which is normally formed on non-copper steels might accelerate corrosion more than the dense adherent film on copper steels. That this idea was right, is shown by the results. We will discuss this feature at greater length a little later.

To clean the rust from the test pieces before final weighing, we used an am-

solution is practically nil. On rusted pieces, due no doubt to electrolysis, it is a little greater, but still negligible compared with the total losses obtained. Furthermore it is approximately the same on all grades used in this test. This is further substantiated by the fact that the order of final failure of the large sheets coincided almost exactly with the

TABLE No. 1

Showing Loss in Ounces Per Square Foot Per Month for Each Period of Exposure in Both Tests at Scottdale and McKeesport, Pennsylvania.

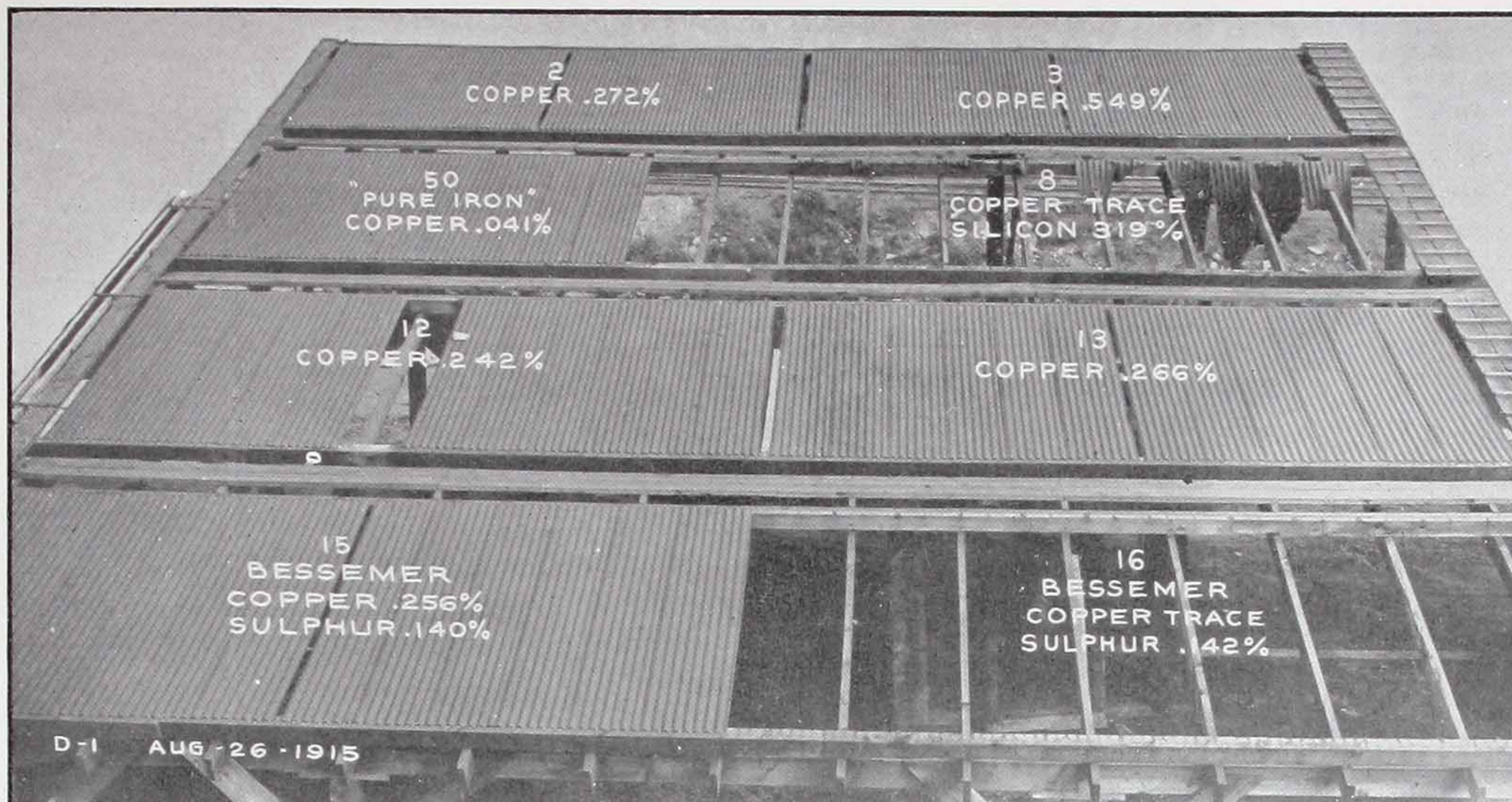
Grade							Annealing Temp.	SCOTSDALE			McKEESPORT			Grand Average	Rank	Element Added
	Carb.	Mang.	Sul.	Phos.	Silicon	Copper		6.5 Months	9.53 Months	Average	8.2 Months	10.9 Months	Average			
2	.06	.41	.039	.032	.004	.272	1400	.1411	.1361	.1386	.1134	.1057	.1095	.1241	9	Copper
							1600	.1405	.1382	.1393	.1041	.1045	.1043	.1218		Copper
3	.06	.43	.045	.041	.004	.549	1400	.1423	.1345	.1384	.1089	.1047	.1068	.1226	8	Copper
							1600	.1374	.1338	.1356	.1043	.0961	.1002	.1179		Copper
4	.07	.43	.039	.036	.004	1.085	1400	.1389	.1319	.1354	.1039	.1007	.1023	.1188	3	Copper
							1600	.1375	.1353	.1364	.0991	.0962	.0976	.1170		Copper
5	.06	.42	.042	.040	.004	2.180	1400	.1314	.1294	.1304	.1005	.0941	.0973	.1138	1	Copper
							1600	.1332	.1303	.1317	.0966	.0905	.0935	.1126		Copper
6	.06	.45	.047	.035	.004	.018	1400	.3723	.4202	.3962	.1843	.2215	.2029	.2996	19	None
							1600	.2632	.3831	.3231	.1634	.2007	.1820	.2526		None
7	.06	.44	.047	.089	.009	.016	1400	.3040	.3564	.3302	.1589	.1682	.1635	.2469	16	Phosphorus
							1600	.2692	.3258	.2975	.1460	.1620	.1540	.2257		Phosphorus
8	.06	.41	.045	.034	.319	.016	1400	.3521	.4747	.4134	.2016	.2027	.2021	.3078	20	Silicon
							1600	.3186	.3909	.3547	.1527	.1656	.1593	.2569		Silicon
9	.06	.43	.047	.036	.007	.017	1400	.3764	.4732	.4248	.2103	.2335	.2219	.3233	22	Aluminum
							1600	.3591	.4758	.4174	.1932	.1890	.1911	.3043		Aluminum
10	.06	.43	.075	.028	.008	.019	1400	.4327	.5144	.4735	.2341	.2926	.2633	.3684	24	Sulphur
							1600	.4211	.5206	.4708	.1960	.2464	.2212	.3460		Sulphur
11	.05	.44	.037	.030	.003	.014	1400	.3746	.4538	.4142	.1923	.2204	.2063	.3103	21	Steel
							1600	.3023	.3693	.3358	.1717	.1823	.1770	.2564		Steel
12	.06	.46	.028	.035	.003	.242	1400	.1386	.1381	.1383	.1073	.1030	.1051	.1217	5	Copper
							1600	.1406	.1394	.1400	.1107	.1056	.1081	.1241		Copper
13	.06	.56	.034	.033	.010	.266	1400	.1388	.1401	.1394	.1043	.1064	.1053	.1224	7	Copper
							1600	.1431	.1377	.1404	.1079	.1073	.1076	.1240		Copper
14	.08	.60	.035	.032	.006	.014	1400	.3344	.3477	.3410	.1785	.1745	.1765	.2588	17	None
							1600	.2729	.3104	.2916	.1788	.1914	.1851	.2384		None
15	.06	.50	.140	.093	.006	.256		.1332	.1458	.1395	.1022	.1020	.1021	.1208	4	Copper
16	.06	.47	.142	.096	.004	.008		.4221	.5018	.4619	.2547	.2353	.2450	.3535	23	None
17	.07	.48	.048	.112	.012	.260		.1280	.1358	.1319	.1028	.0963	.0995	.1157	2	Copper
18	.07	.49	.052	.112	.010	.004		.3301	.3911	.3606	.1895	.1922	.1908	.2757	18	None
19	.07	.29	.029	.016	.009	.265		.1403	.1366	.1384	.1074	.1037	.1055	.1220	6	Copper
20	.06	.31	.039	.018	.005	.102		.1469	.1478	.1473	.1155	.1125	.1140	.1307	10	Cop. & Scale
21	.06	.26	.030	.017	.005	.014		.2849	.2984	.2916	.1649	.1711	.1680	.2298	14	Scale
22	.06	.29	.033	.018	.123	.016		.3026	.3342	.3184	.1604	.1606	.1605	.2394	15	Silicon
23	.06	.29	.035	.068	.006	.015		.2366	.2571	.2468	.1406	.1476	.1441	.1955	12	Phosphorus
24	.06	.30	.027	.016	.004	.014		.2752	.2939	.2845	.1677	.1684	.1680	.2263	13	None
50	.02	.03	.031	.005	.002	.041		.1588	.1577	.1582	.1156	.1178	.1167	.1375	11	

moniacal solution of ammonium citrate. This solution completely removes the rust in about twelve hours, with the minimum attack upon the underlying metal.

Careful experiments show that the attack on bare iron and steel by the above

weight losses obtained on the small pieces, by this method.

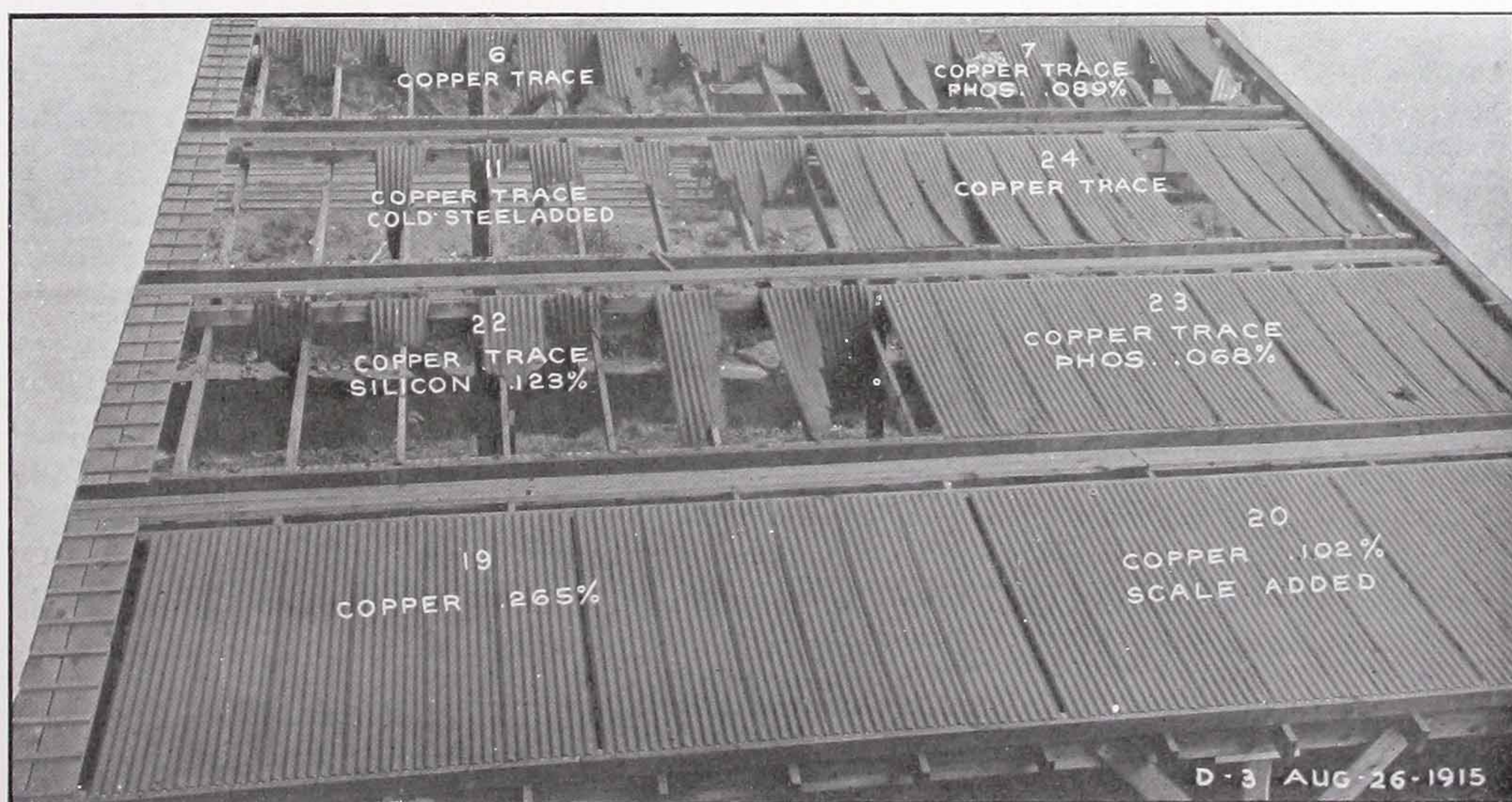
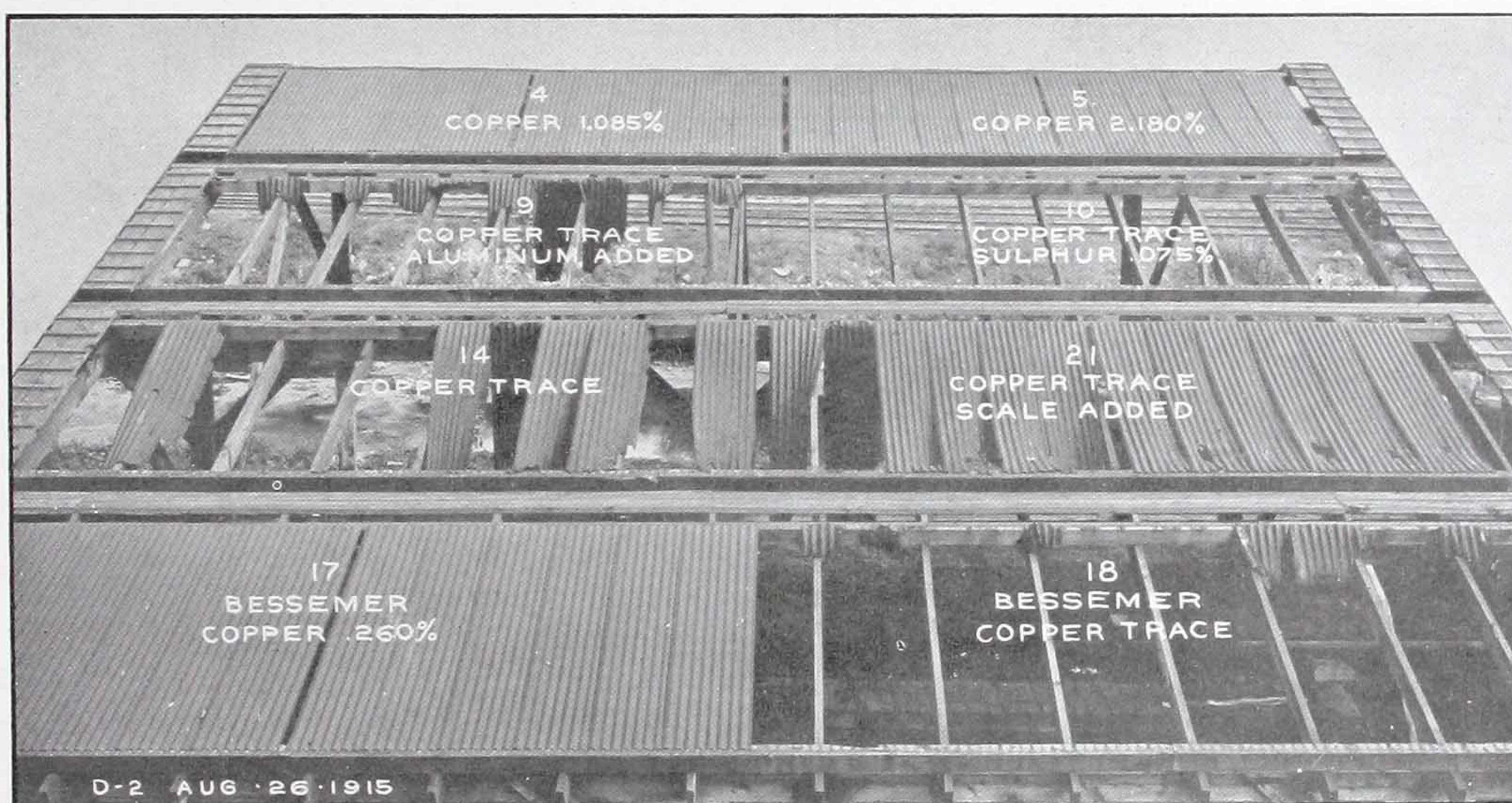
We will not burden this report with details of the various inspections or with detailed tables showing losses of individual test pieces, but will present tables of



FIGS. D 1—2—3.

Scottsdale Test

After about thirteen
and one-half months
exposure.



summaries giving average results. The losses are in each case expressed in ounces per square foot of exposed surface per month, and the results are averages of from six to twelve determinations in each case.

Complete detailed notes may be found at the authors' offices, and are available to anyone who wishes to study them.

Table No. 1 summarizes the results on all grades which were exposed in both locations, and compares losses during the two periods of exposure, and also grand averages. The column headed "Rank" gives the order in resistance to corrosion of various grades—No. 1 being

enth place, while the other grades which have only the usual traces of copper take positions from 12 to 24; the poorest being those to which sulphur was added (No. 10) and which contain high sulphur residually (No. 16), the latter showing losses approximately three times as great as the copper steels.

The addition of aluminum, silicon and cold steel in each case has slightly increased the corrosion rate. (Compare No. 9, 8 and 11 with No. 6.) A phosphorus addition has somewhat lessened the corrosion. (Compare No. 7 with No. 6 and No. 23 with No. 24.) This is in line with some of our previous work.

TABLE No. 2
Showing Loss in Ounces Per Square Foot Per Month for Each Period of Exposure

Grade	Carbon	Manga- nese	Sul- phur	Phos- phorus	Silicon	Copper	McKEESPORT		Average	Element Added
							8.2 Months	10.9 Months		
2X	.06	.49	.033	.029	.004	.290	.1033	.1057	.1045	Copper
3X	.04	.45	.033	.033	.004	.555	.1021	.1035	.1028	Copper
4X	.05	.46	.033	.031	.004	.990	.1038	.1022	.1030	Copper
5X	.05	.46	.031	.025	.011	1.940	.1001	.0979	.0990	Copper
6X	.06	.48	.034	.032	.002	.041	.1293	.1296	.1294	None
7X	.06	.46	.039	.085	.003	.040	.1187	.1210	.1198	Phosphorus
8X	.06	.43	.028	.030	.332	.036	.1352	.1267	.1309	Silicon
9X	.06	.47	.032	.029	.006	.037	.1241	.1301	.1271	Aluminum
10X	.06	.46	.082	.028	.004	.044	.1493	.1810	.1651	Sulphur
11X	.06	.46	.033	.032	.010	.037	.1257	.1314	.1285	Steel
12X	.06	.53	.033	.033	.004	.270	.1046	.1012	.1029	Copper
13X	.06	.41	.031	.022	.006	.314	.1072	.1047	.1059	Copper
14X	.06	.41	.031	.024	.006	.050	.1173	.1167	.1170	None
25	.06	.15	.032	.012	.005	.017	.1922	.2195	.2058	None
26	.06	.16	.030	.012	.004	.404	.1096	.1055	.1075	Copper

best, and No. 24, poorest. In this ranking we have only compared those grades annealed at 1400° F. In this list there are ten grades to which copper was added in amounts from .25 percent., to 2.00 percent.* These have taken the ten highest positions. In these grades there is a remarkable uniformity in the corrosion rate, the greatest loss being .1307 and the lowest .1138. Steels containing copper above .25 percent., give slightly better results, but the difference is so small as to be negligible, especially when considering the added cost.

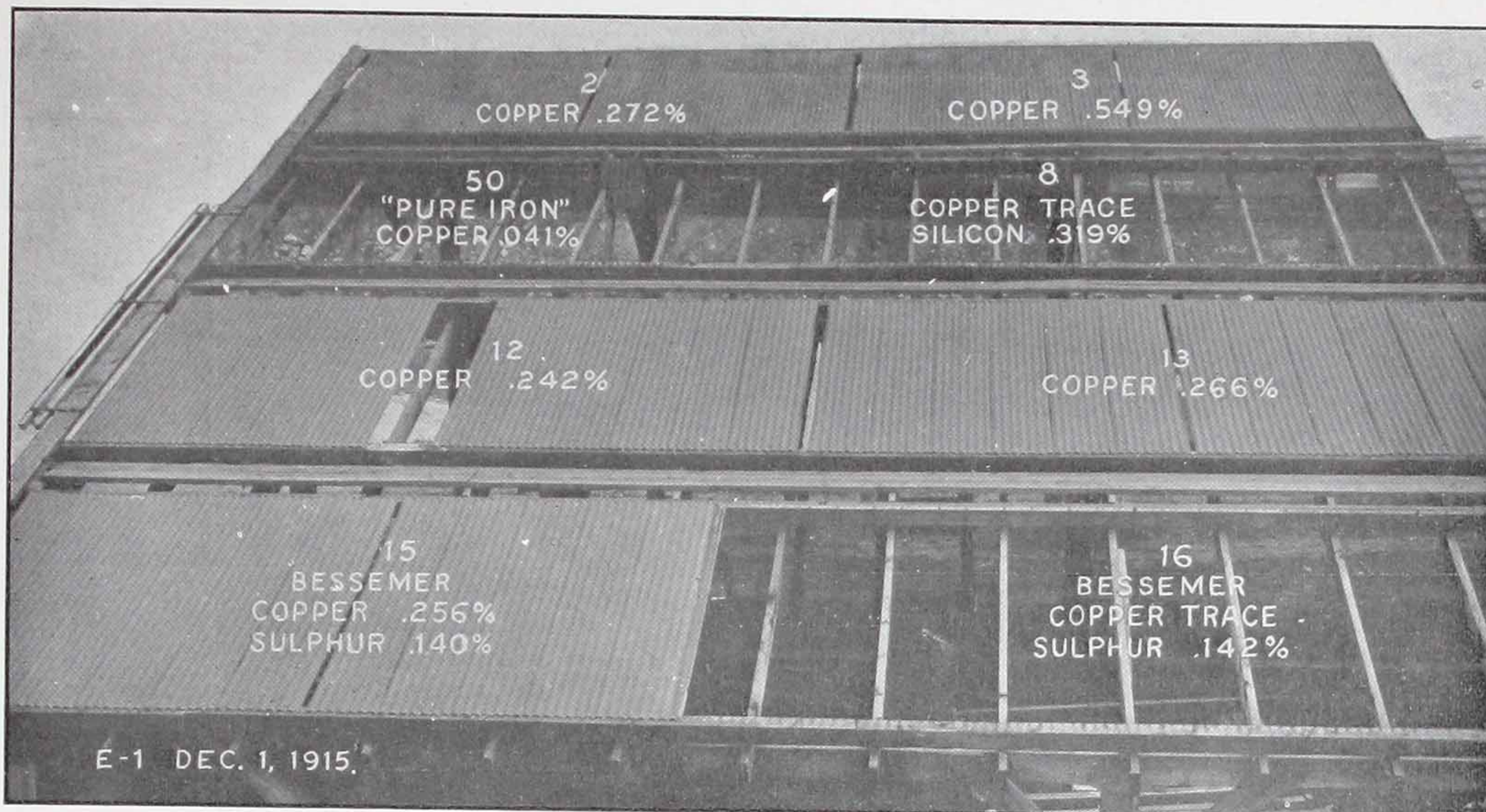
The so-called "pure iron" with a copper content of .041 percent., takes elev-

Grades 19 to 24, although from a heat which was supposed to be highly oxidized, have shown somewhat lower losses than the other heats. From other work we have done, we ascribe this to the somewhat lower sulphur content. (Compare No. 6 and 14 with No. 24.)

In studying the results of tests of Grades 15, 16, 17 and 18 (Bessemer,) we note in No. 16 the accelerating effect of very high sulphur. At the same time, in No. 15 the addition of .25 percent. copper to the same steel has entirely neutralized this influence and the results are quite comparable to those with normal copper steels.

Considering Table No. 2, Grades 2X to 14X, to which the same additions were

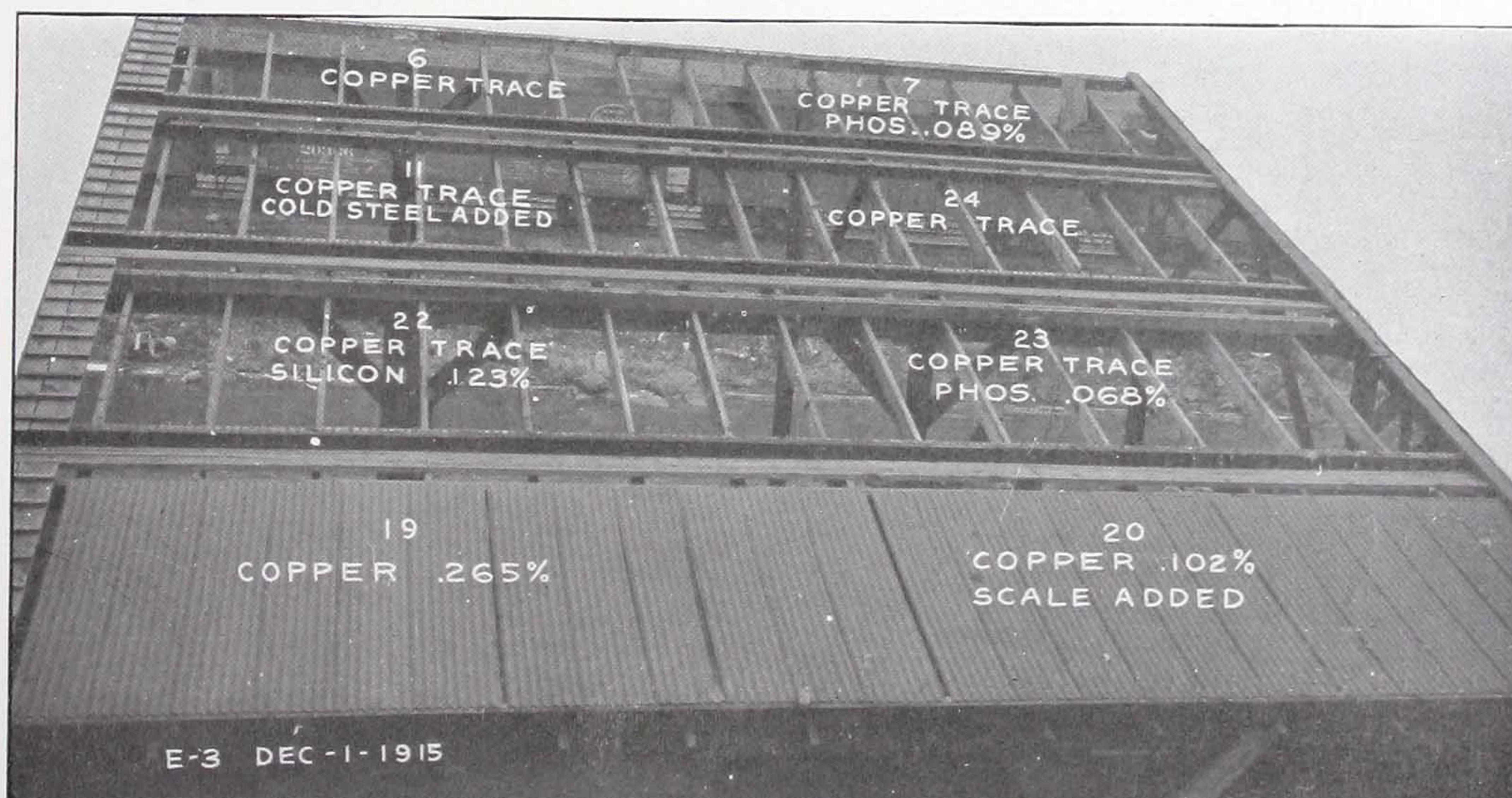
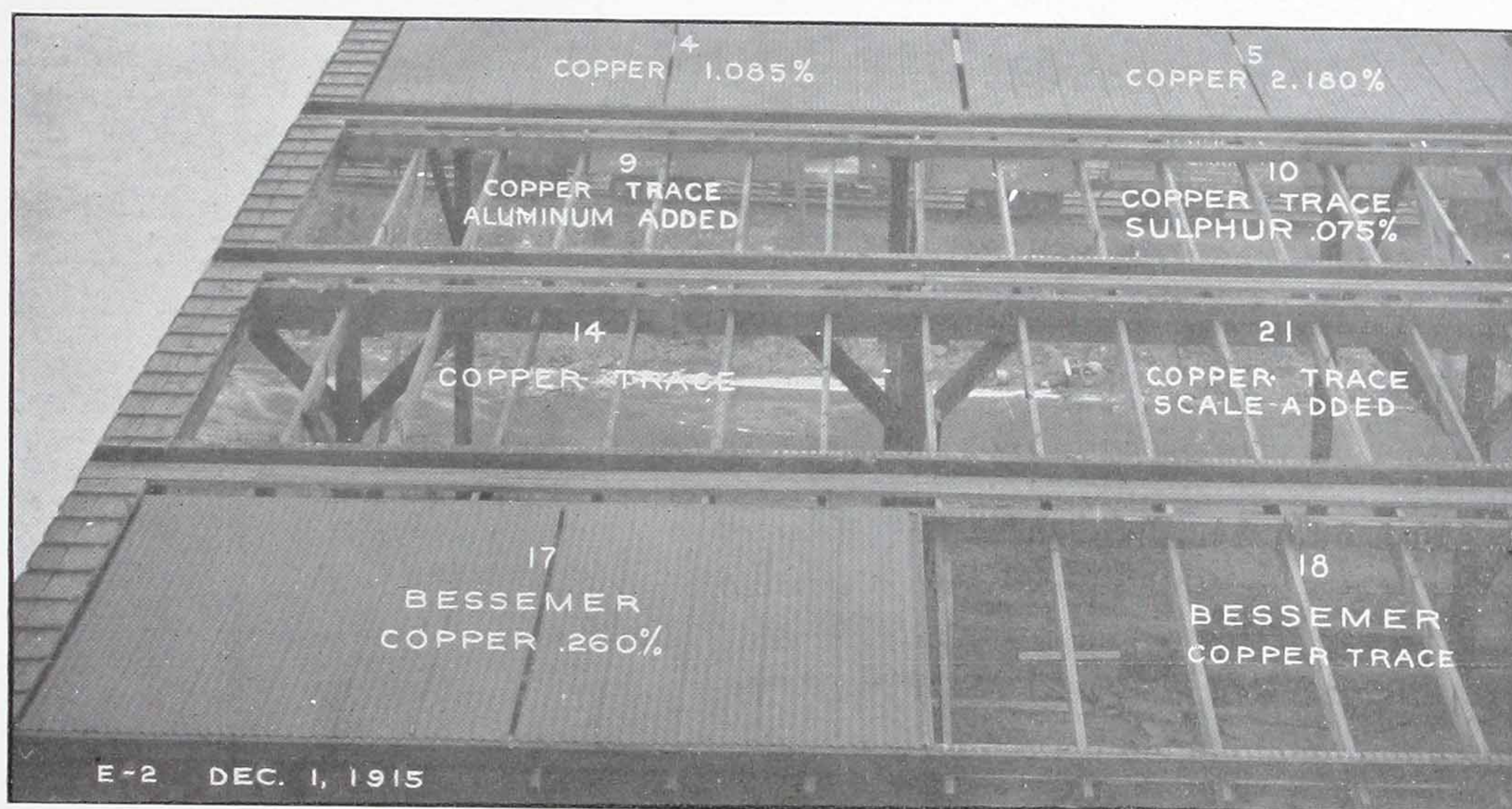
* In grade No. 20, the steel was so wild that it was very difficult to add the copper properly, and some was lost.



FIGS. E 1-2-3.

Scottdale Test

After about seventeen months exposure.



made as to Nos. 2 to 14 (Table 1,) we find that as low a copper content as .04 percent., seems to have materially lessened corrosion. (Compare No. 6X with No. 6, also No. 14X with No. 14, and No. 10X with No. 10, etc.). From the latter we learn that .04 percent copper partially neutralizes the influence of sulphur as high as .082 percent.

The difference is very much less when considering copper steels, the ratio being approximately as follows:

All Steels; 100 at McKeesport to 173 at Scottdale.
Copper Steels; 100 at McKeesport to 133 at Scottdale.
Plain Steels; 100 at McKeesport to 190 at Scottdale.

From table No. 4 we learn that the benefit of higher annealing temperatures in the case of plain steels is approximate-

TABLE No. 3

Average Corrosion per month both periods—Grades 2 to 50—Both Temperatures
(From Table 1)

SCOTTDALE .2596	McKEESPORT .1502
Average Corrosion of Copper Steels per month—Both Temperatures	
SCOTTDALE .1376	McKEESPORT .1037
Average Corrosion of all others per month—Both Temperatures	
SCOTTDALE .3528	McKEESPORT .1857

Panel 25, from a heat to which no de-oxidizer was added, and which was comparatively low in manganese, shows a corrosion rate greater than that of normal Basic Open Hearth Steels, indicating no benefit because of lower manganese but a possible detriment, from the steel not having been deoxidized.

ly 12 percent greater endurance, while for copper steels it is practically negligible.

In determining the loss of the weighed test pieces, the authors adopted the practice of removing them from the racks at different periods. At the end of these periods which were 6-1/2 and 8-1/5

TABLE No. 4

Average Corrosion per month from grand average Copper Steels
(From Table 1)

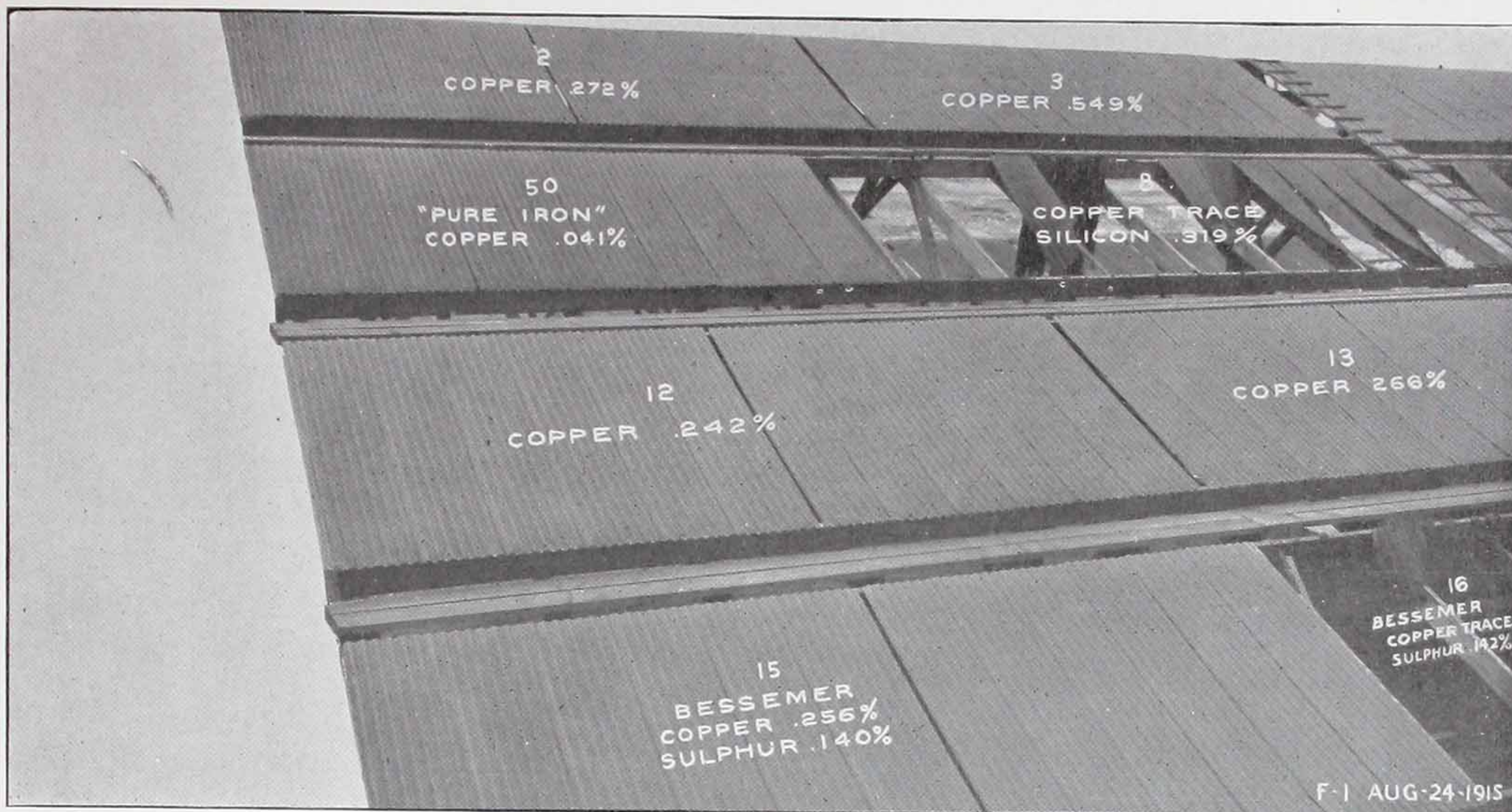
1400 Degrees .1206	1600 Degrees .1196
Average Corrosion per month of all other grades—	
1400 Degrees .3021	1600 Degrees .2686

Panel 26 from the same heat but with copper addition is quite the equal of other steels to which copper was added.

Table No. 3 indicates the relative rates of corrosion, in the two different atmospheres, of all varieties of steel tested.

On plain steels we find that the corrosion in the coke regions, that is, at Scottdale, is nearly twice as great as that at McKeesport in a normal mill district.

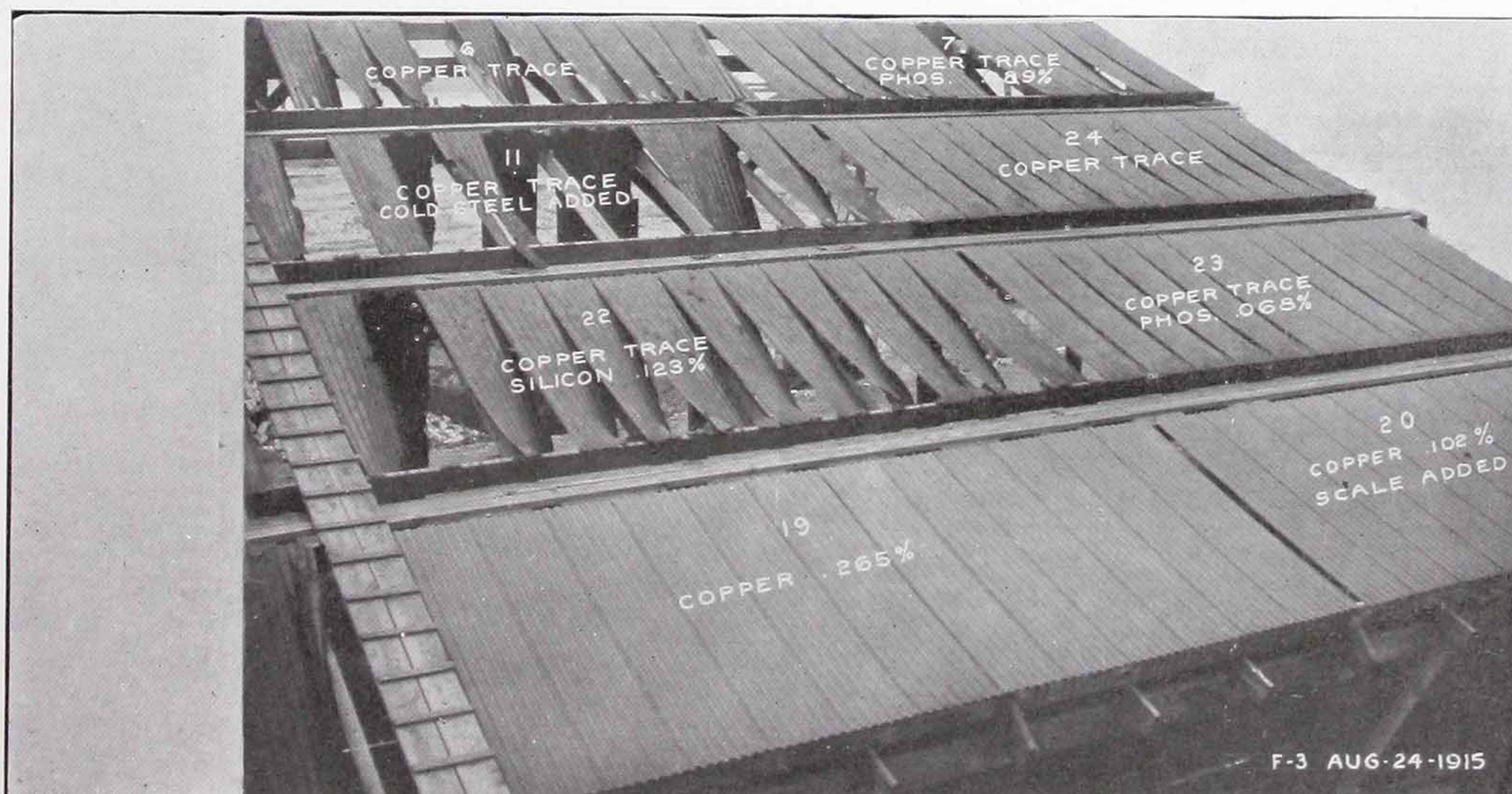
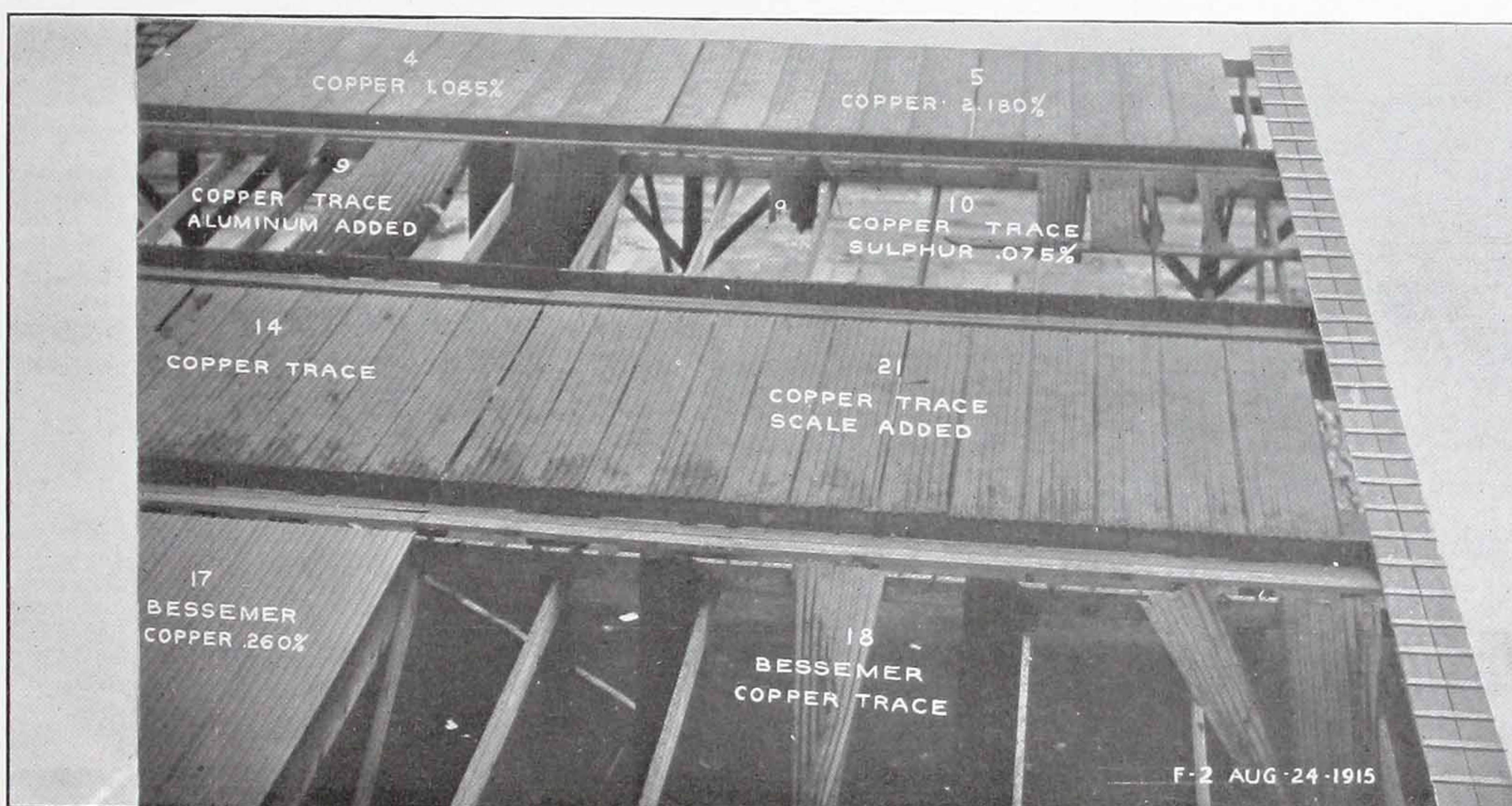
months respectively, we removed one-half of the test pieces and cleaned and weighed them. The remaining half we left exposed for approximately three months longer, at the end of which time they also were taken down, cleaned and weighed. Various conclusions may be drawn from a study of corrosion rates during these two periods of exposure.



FIGS. F 1—2—3.

McKeesport Test
(Mill district)

After about thirteen
and one-half months
exposure.



In Table No. 5 in the Scottdale test we notice that in the first period the rate of corrosion of copper steels was .1379 and of the same steels in the second period, .1369, showing that the corrosion rate does not increase for successive periods of exposure, while with the plain steels, we find a decided increase in the second period over the first, viz: .3383 in the

corrosion ratio being 100 to 177. The "pure iron" containing .04 percent, copper has shown greater total corrosion loss than the copper steels, yet, probably due to its copper content, it ranges itself with the copper steels, in that the corrosion rate is not increased in the second period. The same statement applies to the normal Open Hearth steels

TABLE No. 5

Comparison of Copper Steels and other grades using grades 2 to 24 in each period of exposure.
Results are average corrosion per month, in ounces per square foot.
(From Table 1)

	SCOTTDALE		McKEESPORT	
	Copper Steels	All Others	Copper Steels	All Others
1st Period	.1379	.3383	.1066	.1875
2nd Period	.1369	.5122	.0917	.2343

first to .5122 in the second, a 51 percent. increase in corrosion rate.

Similar results were obtained in the Demmler test as indicated by the figures in the table.

In Table No. 6 we have set apart the copper steels which agree in copper content with the amount used in the average material which is placed on the market,

containing .04 percent, copper, as will be noted by the results on Panels 6X and 14X.

It will also be noted that Grade 6X, a normal Open Hearth steel with .041 percent. copper is nearly as good as No. 50 ("pure iron" also with .041 percent, copper,) while Grade 14X with .05 percent, copper is better than No. 50.

TABLE No. 6

Comparison of Copper Steels of normal analysis with other Steels to which no additions were made.
(From Tables 1 and 2)

	SCOTTDALE			McKEESPORT				
	.25 % Copper Steels (2-12-13-17)	Plain (6-14-18)	"Pure Iron" (50)	.25 % Copper Steels (2-12-13-17)	Plain (6-14-18)	"Pure Iron" (50)	Low Copper Steels (6x)	Steels (14x)
1st Period	.1366	.3456	.1588	.1069	.1841	.1156	.1293	.1173
2nd Period	.1394	.4737	.1554	.0905	.2325	.1244	.1307	.1147

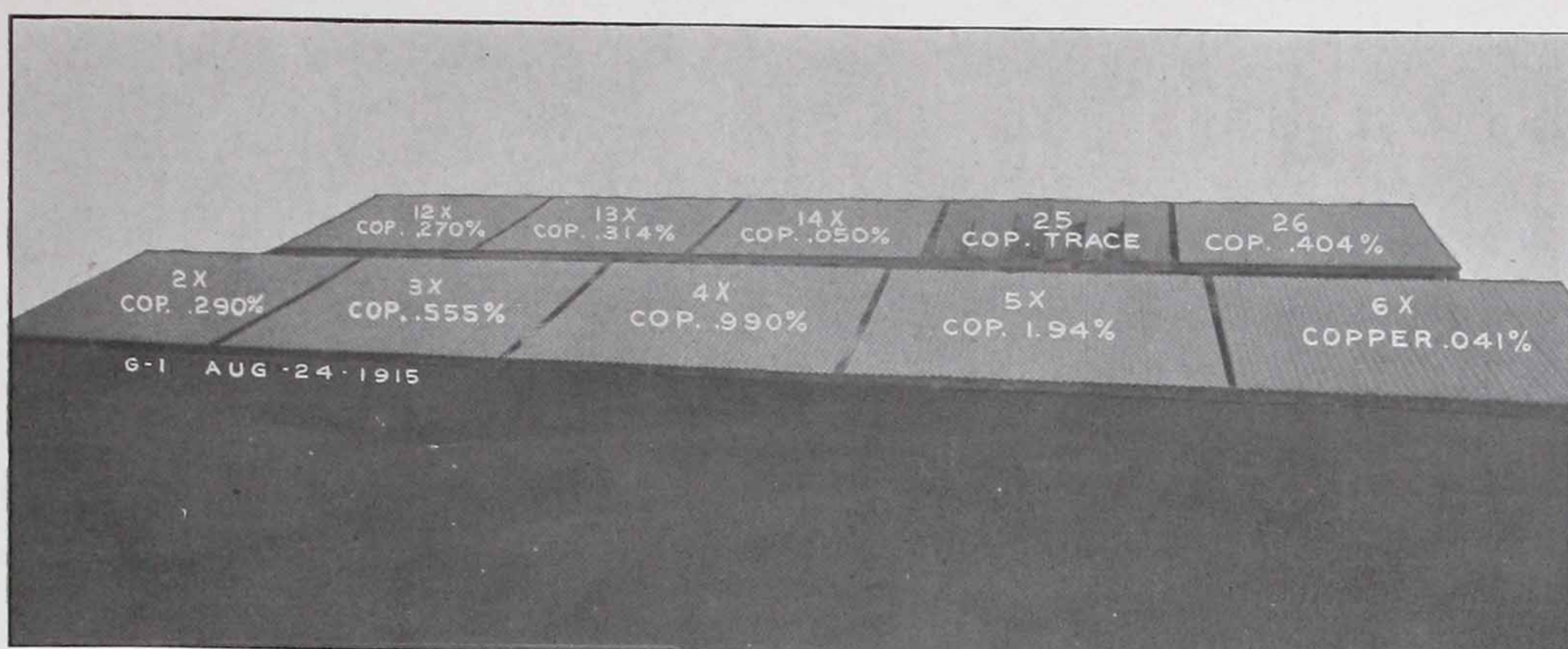
that is, .25 per cent., and we have compared these with plain steels to which no additions have been made, and also with so-called "pure iron." Such comparisons have been made both in the Scottdale test and in the McKeesport test. We find again that with copper steels, as in Table No. 5, the corrosion rate does not accelerate in the second period of exposure, whereas with plain steels, the reverse is true, the

The test roofs have been shown at the different stages of rusting to many parties of metallurgists and other investigators of corrosion problems.

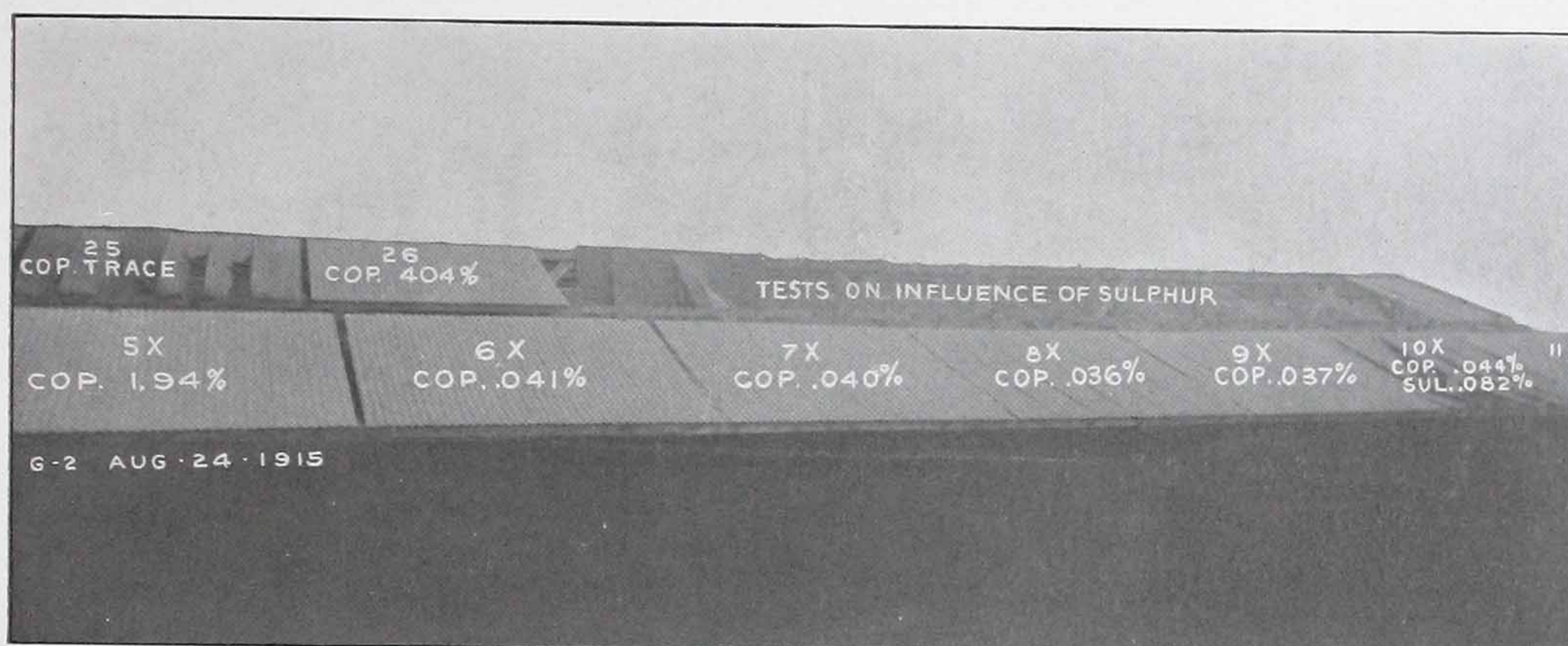
Additional "Pure Iron" Tests

In addition to the tests reported above, one of the authors* has conducted some tests, the result of which give further

* Mr. Handy.



FIGS. G 1—2.
McKeesport Auxiliary
Test
After about thirteen
and one-half months
exposure.



corroborative evidence on the behavior of low copper "pure irons" under atmospheric influences, and also on the progress of rusting during successive periods of exposure. A description of these tests follows:

At the request of one of the authors, two manufacturers of "pure iron" furnished sheets of their material, which were analyzed, corrugated and included in the weather exposure tests at McKeesport. Test pieces were also cut from the sheets and the losses of weight determined by exposure, in Pittsburgh atmosphere, under the same conditions, with copper-bearing steels and plain steels. The analyses of the "pure iron" sheets were as follows:

	Type A Low Copper 1st Lot	Type A Low Copper 2nd Lot	Type B Copper .04 % to .05 %
Carbon	0.013 %	0.020 %	0.014 %
Manganese	0.04 %	0.094 %	0.049 %
Phosphorus	0.004 %	0.005 %	0.003 %
Sulphur	0.030 %	0.018 %	0.033 %
Silicon	0.002 %	0.002 %	
Copper	0.027 %	0.020 %	.045 %
Oxygen	0.031 %		
Aluminum	0.005 %		

The sheets were 26 gauge, except in the case of Type A, 1st Lot, which had a thickness of .022", instead of .0185". They were first exposed on July 16, 1914, November 7, 1914, and August 5, 1914, respectively.

Observations showed that in less than one month, Type A, 1st Lot, was rusting badly and the rust had the light brown color which had been found to be characteristic of the more rapidly corroding steels. In less than two months the same sheets had become very rough, resembling in this respect the most rapidly rusting steels containing added sulphur and silicon. In nine months it had become as thin as paper at the edges. In twelve months it had frayed and broken at the bottom, but did not break transversely when pressed. In fifteen months it had broken through near the bottom, though fairly strong at the upper end. After eighteen months, one square foot of it had rusted away at the bottom, and it was cracked half way up; it cracked

transversely when lightly pressed near the top.

Type A, 2nd Lot, showed a thick, light brown rust after about two months' exposure. After four months, there was a thick, light brown scale. After six months, the sheets were thin at the bottom, but could not then be broken by light pressure. After nine months, the sheets were rusted away at the bottom. One sheet was full of holes in the lower half and the rusting had proceeded further than in the case of the 1st Lot at this period. After twelve months the sheets had become detached and were rusted so badly that they could be broken easily by hand in any part.

The more rapid corrosion of the second lot of this "pure iron" is believed to be due to the lower copper content.

Type B. It will be noticed that this type of "pure iron" contained more than twice as much copper as the "pure iron" of Type A. The percentages of copper in the different sheets were .043, .044 and .048, which places it in the class with "pure iron" in the main test and with the sheets 6X and 14X, already described as being far more durable than plain steel or "pure iron" of Type A, especially in the 2nd Lot. After six months, they were graded as showing no more corrosion than the copper bearing steels which had been exposed for seven months. After eight months they were graded as being no longer as resistant to corrosion as the copper steels containing approximately 0.25 percent., copper. The rust was quite rough, resembling 7X, 14X and the "pure iron" in the main test. After eleven months, while the rust was rough and deep, there was no perceptible thinning at the edges and no sagging. After fourteen months, one sheet broke when lightly pressed. After seventeen months, one sheet was perforated and cracked. The second sheet was cracked and had a small perforation. The third sheet was not then broken through.

The quantitative weight losses of the test pieces exposed for approximately

equal periods, though at slightly different seasons, in the Pittsburgh atmosphere were as follows:

	Time	Loss in ounces per sq. ft.
Type A, 1st Lot	6 mos. (Oct. to Apr.)	2.70
Type A, 2nd Lot	5 1/2 mos. (Nov. to Apr.)	2.34
Type B,	5 2/3 mos. (Oct. to Apr.)	1.64

The test pieces, of which there were three in each case, were, after cleaning with ammonium citrate solution and weighing, exposed for three months longer.

	Time	Loss in oz. per sq. ft.	Copper per-centage
Type A, 1st Lot	3 mos. (May to Aug.)	1.26	.027
Type A, 2nd Lot	3 mos. (May to Aug.)	1.66	.020
Type B,	3 mos. (May to Aug.)	0.99	.045

It will be seen that, when exposed under exactly the same conditions, the losses of weight were inversely proportional to the small and slightly varying copper percentages.

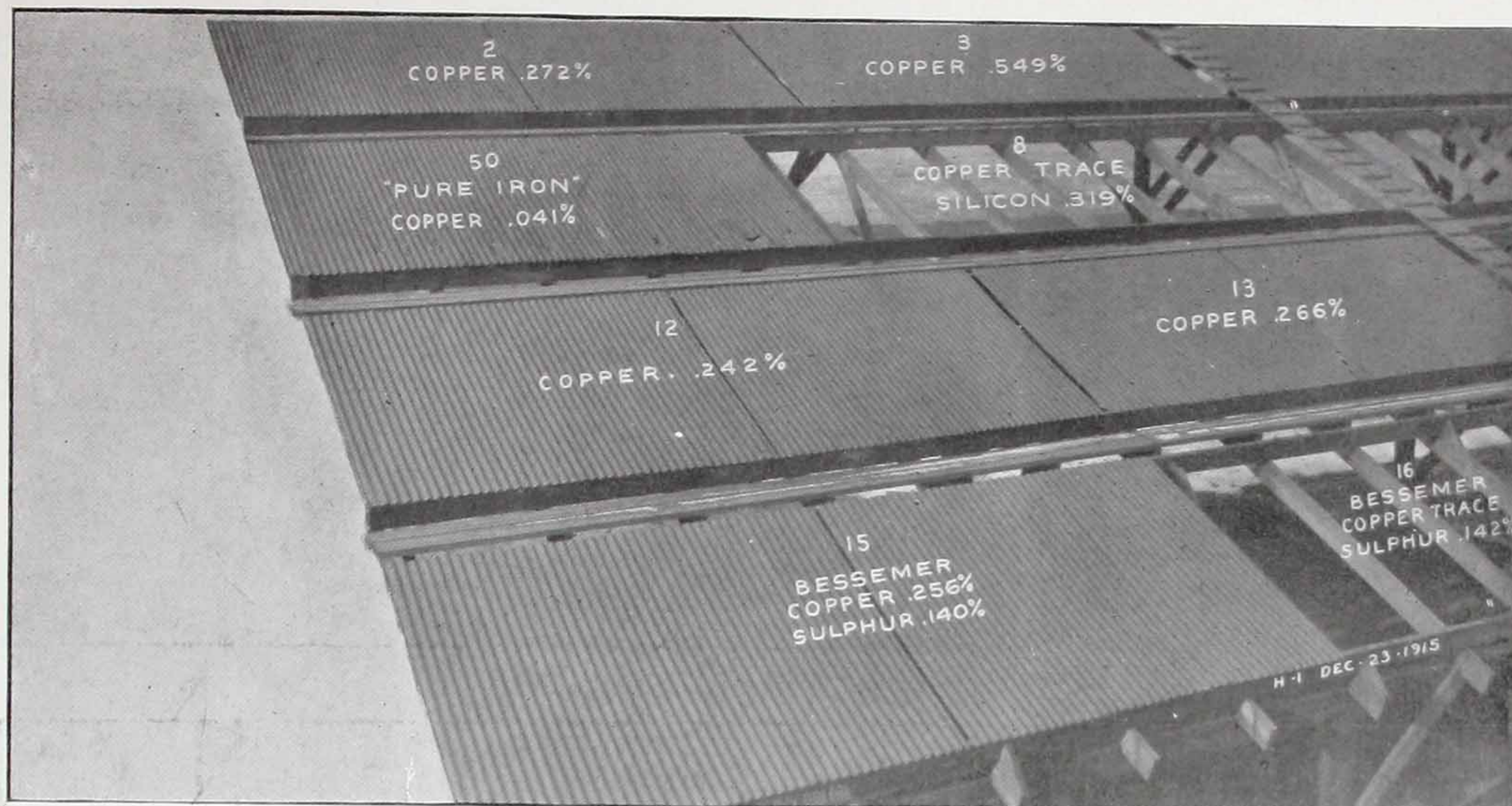
The following experiment shows the comparison between weight losses during one, two and three months' exposures of *separate* test pieces of "pure iron," Type A, 2nd Lot.

	Loss in oz. per sq. ft.
June 1st to July 1st	0.74
June 1st to August 1st	1.42
June 1st to September 1st	2.27

It had been noticed in other experiments that the copper steels showed less loss of weight for equal periods of exposure after the first dense rust coating had formed. These experiments show that the nearly equal corrosion loss during the second month and the greater corrosion loss during the third month places this low copper "pure iron" in the same class of inferior weather-resisting material with plain steel free from copper.

Further Corrosion Rate Determinations

Corrosion losses, in ounces per square foot of Copper Steel, Plain Steel and "Pure Iron."

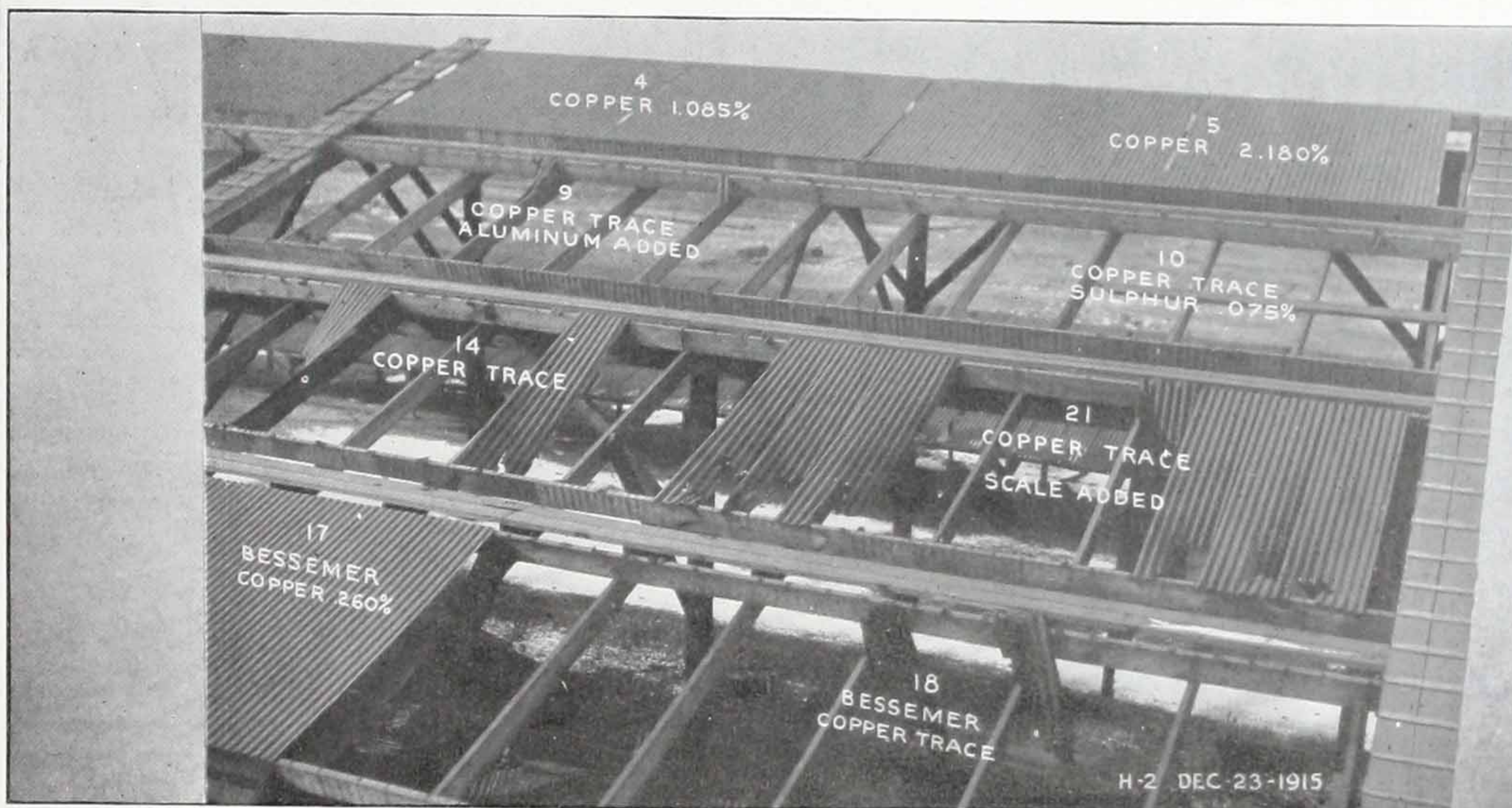


FIGS. H 1—2—3.

McKeesport Test

After about seventeen and one-half months exposure.

Panel No. 50 showing signs of failure.

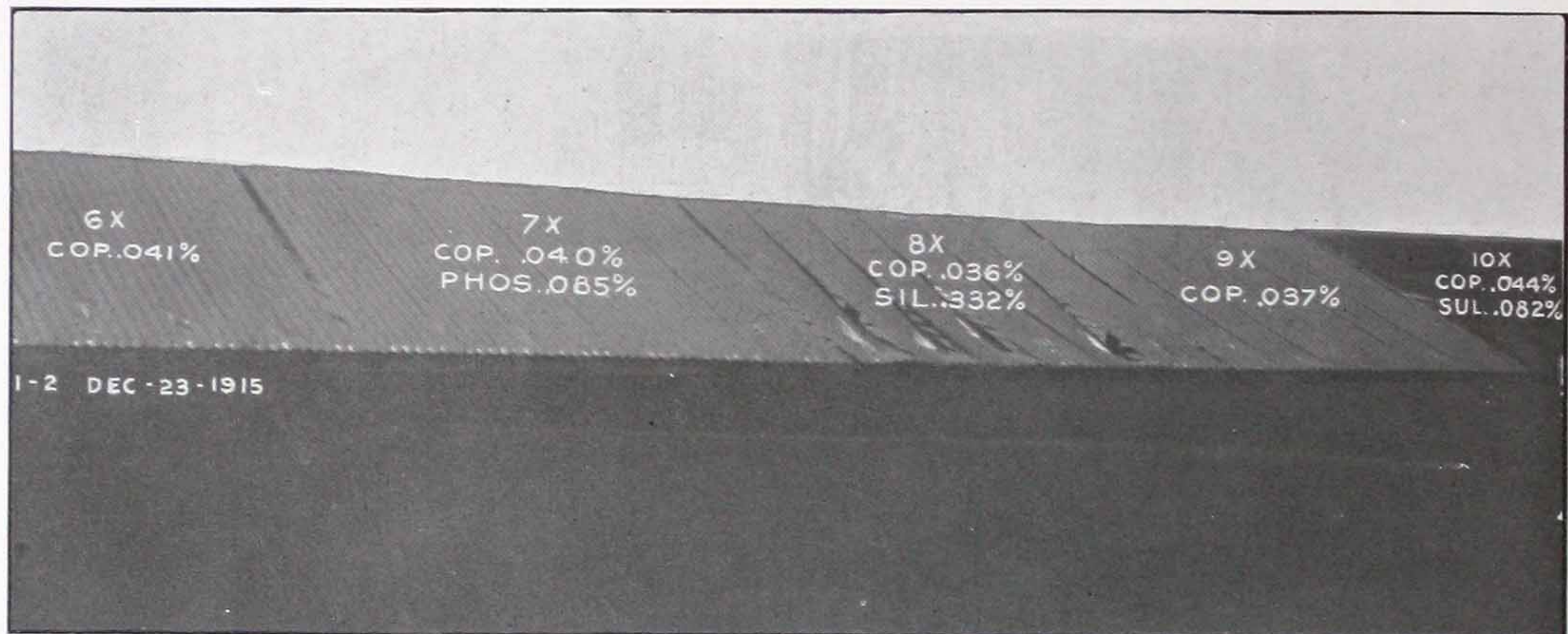
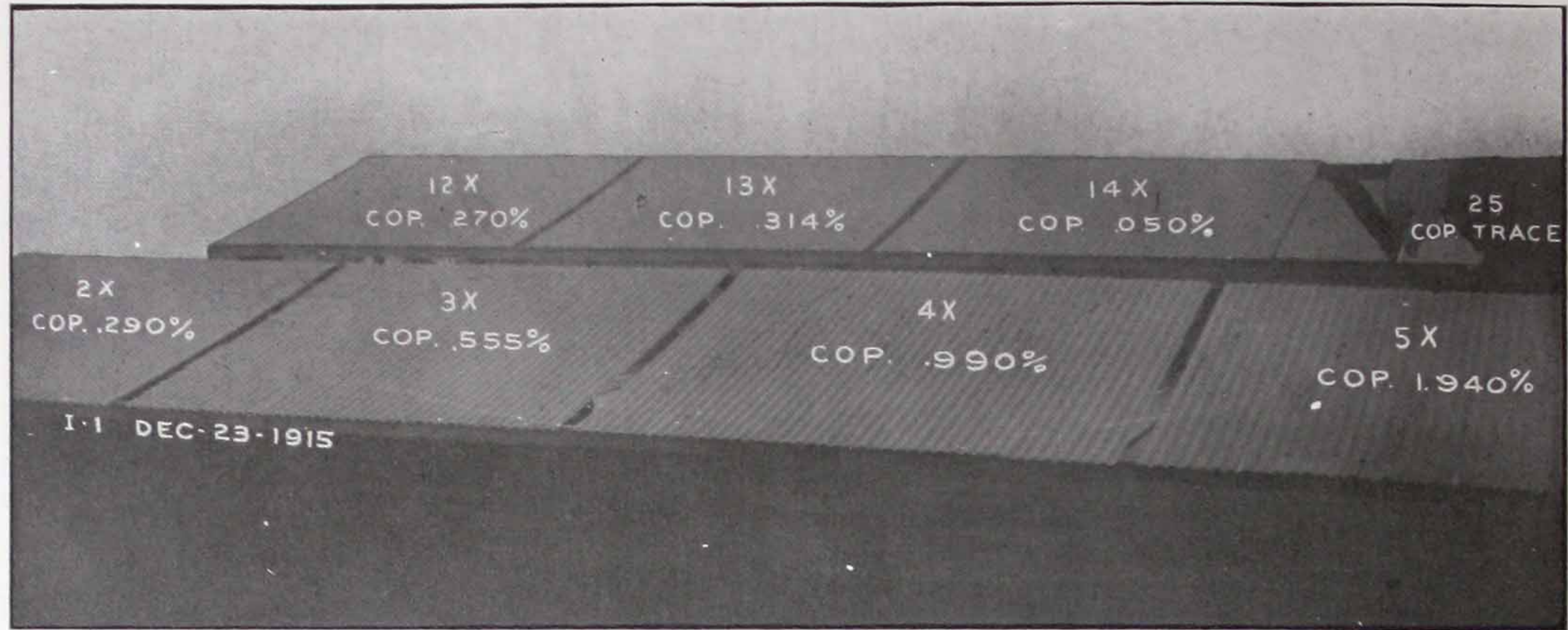


FIGS. I 1—2.

McKeesport Auxiliary
Test

After about seventeen
and one-half months
exposure.

Panel No. 6X showing
signs of failure.



Test pieces were exposed in racks for *one month periods* in the Pittsburgh atmosphere. The results in the following table do not represent progressive rusting, a new test piece having been exposed on the first of each month.

	Copper Bearing Steel		"Pure Iron"
	.25 % Copper	Plain Steel	.045 % Copper
May corrosion loss	.52	.90	.64
June corrosion loss	.38	.65	.49
July corrosion loss	.56	.95	.76
August corrosion loss	.54	.75	.68

Corrosion losses, in ounces per square foot of Copper Steel, Plain Steel and "Pure Iron."

Test pieces were exposed for from one to five month periods in the Pittsburgh atmosphere with the following results. These results represent progressive losses, six (6) pieces having been exposed at the start and one taken down at a time at the end of each month.

	Copper Bearing Steel		"Pure Iron"
	.25 % Copper	Plain Steel	.045 % Copper
One month	.52	.90	.64
Two months	.64	1.82	.92
Three months	.95	3.00	1.41
Four months	1.13	3.64	1.46
Five months	1.13	4.41	1.61
Six months	1.17	5.53*	1.76

From the above tables, it will be noticed that the progress in rusting under the original rust coat is much more rapid in the case of the plain steel than in the case of the copper bearing steel, and materially less rapid in the case of the copper steel than in the case of the "pure iron." It should be noted, however, that this "pure iron" contains enough copper to account for its approximating in corrosion resistance the copper bearing steel.

It is of great interest to note that corrosion practically stopped in the case of the copper bearing steels after the fourth month. The rust had formed an efficient protective coating.

* This piece of plain steel was at this time reduced from an original weight of 18.3 grams to 0.9 grams, and was wholly disintegrated.

CHART DRAWN FROM TABLE No. 7.

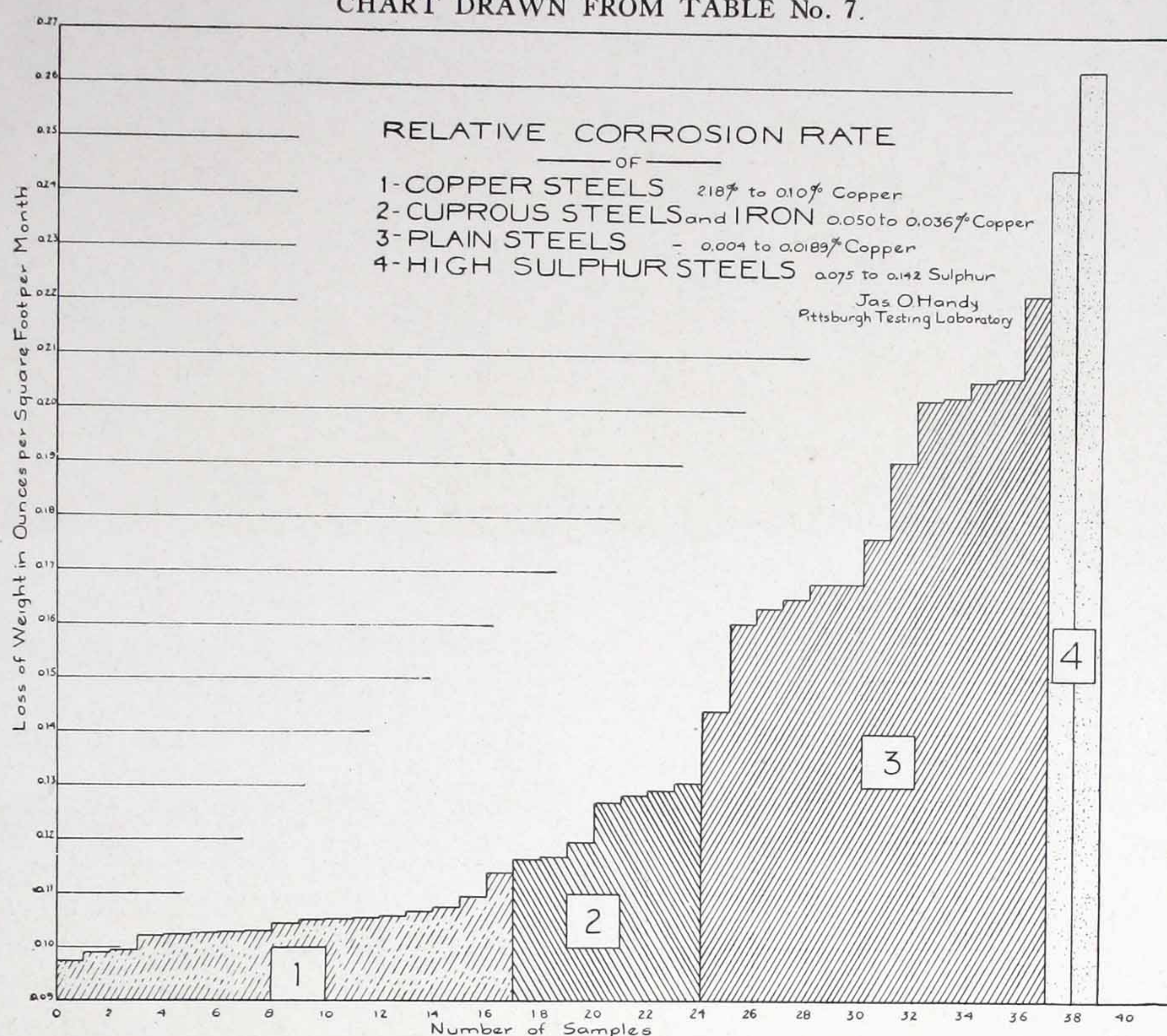


TABLE No. 7

Showing Grades in McKeesport Test Arranged in Order of Their Corrosion Resistance.
Corrosion Losses in Ounces Per Square Foot Per Month (11 Months).

Rank	Element Added	Copper	Sulphur	Loss: Average	Serial No.
1	Copper	2.18 %	.042 %	.0973	5
2	Copper	1.94 %	.031 %	.0990	5X
3	Copper	0.26 %	.048 %	.0995	17
4	Copper	0.256 %	.140 %	.1021	15
5	Copper	1.085 %	.039 %	.1023	4
6	Copper	0.555 %	.033 %	.1028	3X
7	Copper	0.270 %	.033 %	.1029	12X
8	Copper	0.990 %	.033 %	.1030	4X
9	Copper	0.290 %	.033 %	.1045	2X
10	Copper	0.242 %	.028 %	.1051	12
11	Copper	0.266 %	.034 %	.1053	13
12	Copper	0.265 %	.029 %	.1055	19
13	Copper	0.314 %	.031 %	.1059	13X
14	Copper	0.549 %	.045 %	.1068	3
15	Copper	0.404 %	.030 %	.1075	26
16	Copper	0.272 %	.039 %	.1095	2
17	Copper & Scale	0.102 %	.039 %	.1140	20
18	None: "Pure Iron"	0.041 %	.031 %	.1167	50
19	None	0.050 %	.031 %	.1170	14X
20	Phosphorus	0.040 %	.039 %	.1198	7X
21	Aluminum	0.037 %	.032 %	.1271	9X
22	Steel	0.037 %	.033 %	.1285	11X
23	None	0.041 %	.034 %	.1294	6X
24	Silicon	0.036 %	.028 %	.1309	8X
25	Phosphorus	0.015 %	.035 %	.1441	23
26	Silicon	0.016 %	.033 %	.1605	22
27	Phosphorus	0.016 %	.047 %	.1635	7
28	Sulphur	0.044 %	.082 %	.1651	10X
29	Scale	0.014 %	.030 %	.1680	21
30	None	0.014 %	.027 %	.1680	24
31	None	0.014 %	.035 %	.1765	14
32	None	0.004 %	.052 %	.1908	18
33	Silicon	0.016 %	.045 %	.2021	8
34	None	0.018 %	.047 %	.2029	6
35	None	0.017 %	.032 %	.2058	25
36	Steel	0.014 %	.037 %	.2063	11
37	Aluminum	0.017 %	.047 %	.2219	9
38	None	0.008 %	.142 %	.2450	16
39	Sulphur	0.019 %	.075 %	.2633	10

Summary

Sheet steel or iron containing copper shows greatly increased corrosion resistance when exposed to atmospheric conditions. The most effective amount of copper to be used for this purpose is approximately .25 percent. Smaller amounts of copper down to as little as .04 percent., have considerable influence in lessening corrosion, but the results are not as good as with the higher amount mentioned above. Work previously done by one of us has indicated that .15 percent. copper is in nearly all cases as efficient as .25 percent. Higher amounts of copper up to 2 percent., give little or no added benefit. Copper is as necessary, in the so-called "pure irons," to insure corrosion resistance as it is in normal Open Hearth and Bessemer steels.

The addition of phosphorus to Open Hearth steel slightly lowers the corrosion rate.

Silicon while probably without effect in the amounts normally present in Open Hearth and Bessemer steels accelerates

corrosion when added in amounts from .10 percent., to .30 percent.

The addition of small amounts of aluminum probably has little influence on corrosion. These tests indicate it to be harmful rather than beneficial.

The addition of sulphur to steel greatly increases the corrosion rate and when residually present in abnormal amounts, it is probably also detrimental from a corrosion standpoint.

The addition of cold steel to molten steel does not lower the corrosion rate, but, if it has any influence at all, it is to increase the corrosion.

Results obtained by loss in weight determinations on small test pieces are found to be accurate and valuable when determining the relative corrosion resistance of various sheet metals. The method of cleaning such test pieces with ammoniacal ammonium citrate solution is found to be the most convenient and accurate thus far investigated.

Second Edition

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